DÆDALUS

JOURNAL OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES

Modern Technology: Problem or Opportunity?

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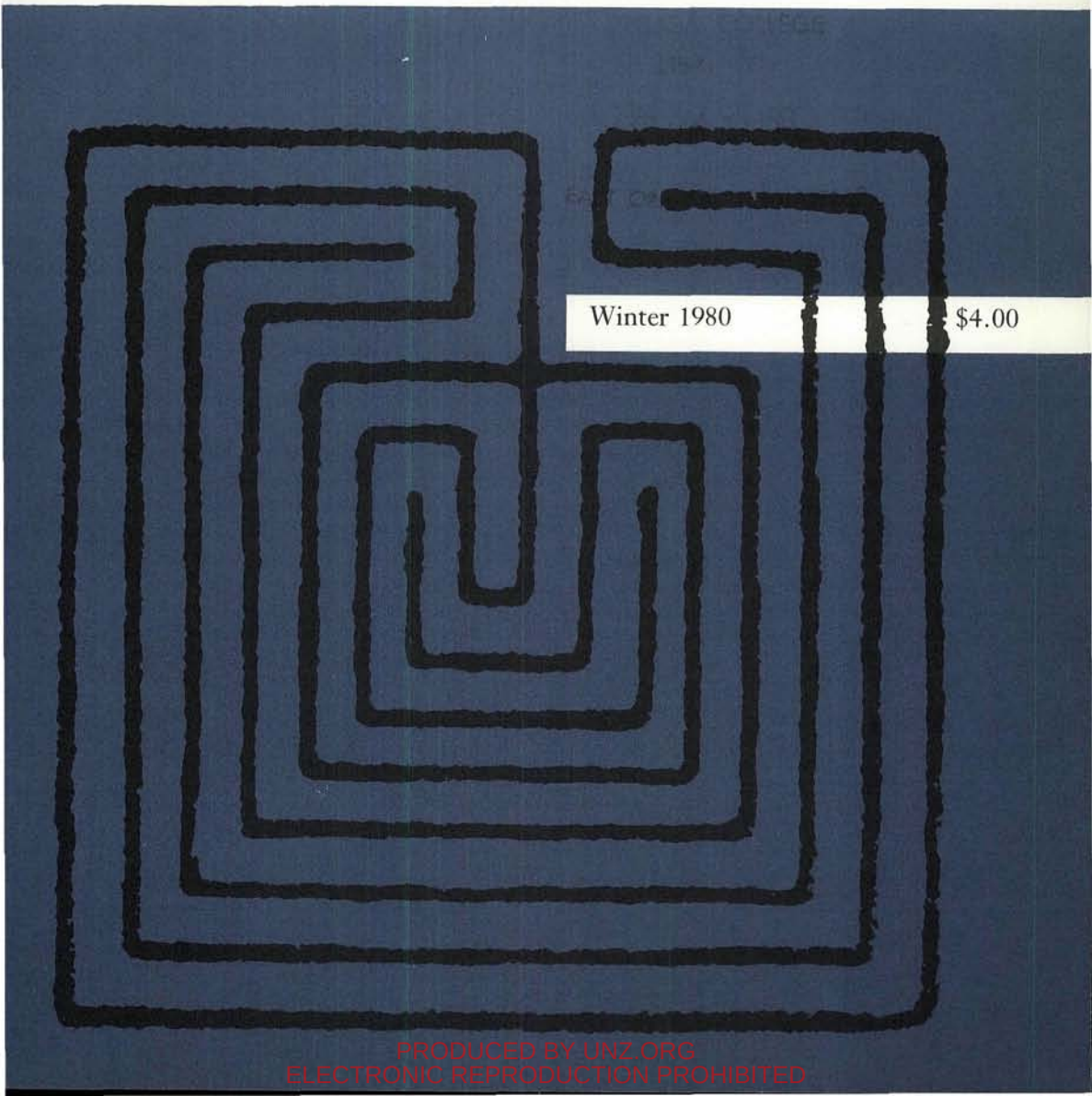

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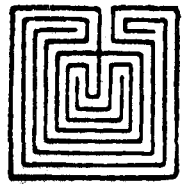

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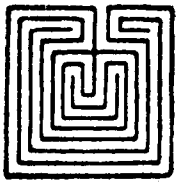

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WINTER 1980: MODERN TECHNOLOGY: PROBLEM OR OPPORTUNITY?

Issued as Vol. 109, No. 1 of the Proceedings of the American Academy of Arts and Sciences

ADVISORY GROUP

Harvey Brooks, Alfred Chandler, Norman Dahl, Edward E. David, Jr., Loren Graham, Stephen R. Graubard, Albert Hirschman, Gerald Holton, David Landes, Michael Maccoby, Elting Morison, Robert S. Morison, Walter Rosenblith, Merritt Roe Smith, Raymond Vernon, Joseph Weizenbaum, Langdon Winner

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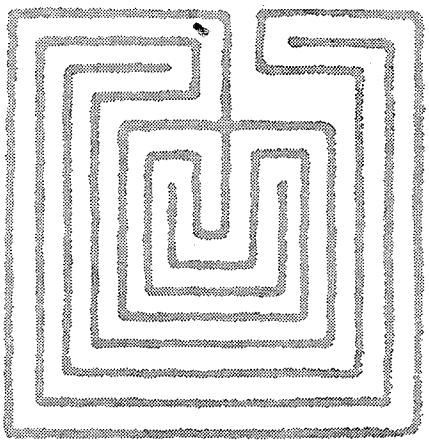

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Preface to the Issue, "Modern Technology: Problem or Opportunity?"

THIS ISSUE OF *Daedalus* asks many more questions than it answers. An argument could be made that its principal purpose is to raise questions and that every other interest is secondary. The Editors, following literally the injunctions of those who helped plan the study—whose deliberations are embodied in the abbreviated and edited transcript that opens the volume—were concerned mostly with producing an "issue on issues," one that would broaden the public's perceptions of what is involved in modern technology, going beyond the subjects commonly discussed in certain of the more familiar public debates of the day.

That technology commands at this time an interest greater perhaps than any it has enjoyed in the past is incidental to a larger fact that a good number of the authors in this volume insist on: modern technology needs to be seen as something more than machinery. Too many of us still tend, however unwittingly, to think and write about technology in terms more appropriate to the nineteenth century than to the twentieth, emphasizing the mechanical and the entrepreneurial to the disadvantage of the systemic. A better definition of modern technology insists that it be thought of not as a collection of artifacts, however sophisticated and complex, but as a system whose social, cultural, intellectual, managerial, and political components are seen as integral to it. This view carries an explicit acceptance of the idea that we have gone beyond the age of the machine. If there is some concern in this volume to distinguish between science and technology, to consider how each relates to the other, and why these relations are more complex than is sometimes imagined, there is a no less compelling interest in asking whether technology is culture-dependent, and what we know about why and how certain societies come to receive and use the technologies they adopt. This is part of the larger questions of how technological innovation takes place in the modern world and why it follows the patterns that it does. How, indeed, are we to think about the evolution of technologies and of whole technological systems? Are biological paradigms helpful, or ought our purpose to be to think in wholly other terms?

Because so many of these issues are novel, or at least appear to be so, not following precisely the lines of inquiry that the mass media seem to prefer, it is easy to misconstrue their significance. These essays address themselves to certain of the more fundamental issues of our times: they seek to explain why the unintended social and other consequences of technological innovation are so

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frequently disconcerting to so many; they ask why, if technology is indeed knowledge, certain societies find it so difficult to use that knowledge, even where they show such an obvious interest in doing so. Many who read this volume will ask why technology remains today so much a subject of moral dispute, and whether the close analysis of the complex "systems" described in these pages is much helped by the intellectual climate now common in the West.

If all discussion of modern technology presumes a willingness also to discuss contemporary education, the nature and limits of that discussion need to be reflected on. Are we to concern ourselves primarily with preparing for specific professions—medicine, engineering, management, and the like? Or, ought we to be equally concerned with instruction in law, divinity, and the arts and sciences more generally? What rationale do we have for emphasizing one rather than another?

Given the new role of government in every aspect of modern technological development, it is clearly no longer enough to be concerned with governmental activity in respect to taxes and tariffs, or even with the more substantial issues raised by its involvement in employment policy and public regulation of industry. A larger political capability and understanding of public policy is clearly called for. Who, in our times, can be depended on to provide these? How is this to be accomplished?

Who, for example, will concern himself with productivity, realizing that the issue transcends the willingness of workers to be contented, and that it involves more than the management of money by private investors and by bureaucrats making use of ingeniously calibrated public expenditure programs? Who, given the complexities of our "systems-oriented culture," can look out at the variegated technological scene of today and make sense of it, explaining why and how American technology resembles and differs from that of the Soviet Union, and how both compare with that of Japan? Who can take in the uniformities created by the practices of multinational corporations, and yet reconcile these with the elements that remain culture-specific? Who has the interest to explore why so much of the thinking on technological change in the 1950s and 1960s was so naive, so culturally and historically innocent? Who can do this with a modicum of irony and a sense of charity? Indeed, is it at all obvious that we are doing better today in understanding modern technology, its problems and opportunities, than we did in the past? What evidence do we have for believing that?

This issue is only the first that *Daedalus* proposes to publish on modern technology. We believe that the subject will command even greater attention in the future. We hope to be able to make a contribution to the ongoing study of many of the complex issues raised in this volume. Thanks are due to the Alfred P. Sloan Foundation for providing a grant that made the planning of this issue possible. Together with funds available from the Ford Foundation for interdisciplinary study, we were able to move ahead to publish this "issue on issues." We are greatly indebted to both foundations and to those who advised us; their help has proved invaluable.

S.R.G.

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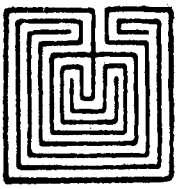

Some Issues of Technology

From a conference held in Cambridge, Massachusetts, April 30, 1979.

Participants

Harvey Brooks
Alfred Chandler
Norman Dahl
Edward E. David, Jr.
Stephen R. Graubard
Albert Hirschman
Gerald Holton
David S. Landes
Michael Maccoby
Elting Morison
Robert S. Morison
Walter Rosenblith
Merritt Roe Smith
Raymond Vernon
Joseph Weizenbaum
Langdon Winner

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GRAUBARD: Technology dominates the news today and figures in our thinking in ways that would have seemed almost inconceivable just a few decades ago. We all know how preoccupying are the implications of soaring energy costs; we are painfully aware also of the uncertainties of supply, of the remoteness of safe and cost-effective alternatives to the fuels that are now common. The industrial expectations of yesterday suddenly seem naive, almost innocent; we wonder whether we have been too sanguine for too long. Have we been insufficiently attentive to the *real* problems of development in the modern industrial world? But, what, indeed, are those problems? Are they social, political, economic, perceptual? Ought we to be largely preoccupied with productivity, with technological innovation and invention? Is this a problem for all industrial societies, for some, for a few? Why has it become so paramount an issue in the United States at this time? If we are to anticipate the issues of the 1980s, ought our chief concern to be with the hazards of technology, with the elements of "risk" that are increasingly coming to the fore in all public discussion of major industrial options and alternatives? Are such themes suitable to treatment in a journal like *Daedalus*, or ought we to be aiming for something quite different? Is this, for example, an opportune time to raise questions about the nature of modern industrial society? Is too much of our reflection about technology too machine-oriented? Are we in fact asking questions about specific techniques when we ought to be asking more general questions about the nature of modern culture? Yet, how is it possible to do that without emphasizing the immense complexity and variety of that culture? Do we know how to treat such issues? Why do they figure so rarely on the public agenda of those who concern themselves with technology in the modern world?

DAVID: Let me start by saying, I think one of the opportunities is to have an issue on issues, because the issues themselves are really not well defined. We can think of specific issues, of course, that are reasonably defined, but the whole technological question is, I think, fair game.

BROOKS: I think the question of purpose is rather central. It seems to me that one of the issues we have to address is what we think the role of technology will be or must be in the present *problematique* of civilization. There is a tremendous divergence of opinions on that question. There are those who, like myself, think it is absolutely essential for survival, and there are others who think in fact it is almost the opposite.

DAVID: There is a bit of confusion about that whole question, Harvey, and I think it is a very good one.

BROOKS: It seems to me that because technology opens up options, it takes a strong value system to control the choice of options; and so, where technology is disastrous is where it enters a culture or a social situation with a weak value system and very little sense of collective welfare.

WEIZENBAUM: I would like to endorse what has just been said, especially because I think our culture has a weak value system and little use of collective welfare, and is therefore disastrously vulnerable to technology. As you all know, the computer revolution has been announced a great many times. We are now being bombarded by a still new announcement—the microcomputer revolution, the home-computer revolution. At least one component of the fuel for the develop-

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ment of this technology is the complexity of society. This alleged complexity is said to be so enormous that the computer is necessary just to make it possible to maintain the most basic societal functions. There may be other reasons for using computers here and there, but I think this is the chief underpinning for the belief in the *necessity* of widespread computerization. This complexity is really of two kinds. There is structural or organizational complexity, where there are principles of organization by means of which the complexity can be comprehended: one has a theory; one can understand it. Consider, for example, the street map of Manhattan. It does not take much to understand that, even though it is in a certain sense complex. Then there is the kind of complexity that is really incoherence. This derives in society from a lack of tradition or from an impermanence of values. It seems to me that it is precisely in the latter case that technological fix becomes most attractive and is at the same time the most tempting invitation to a Faustian bargain.

MACCOBY: Perhaps you can make a more general point of education, not just about the computer but about all forms of social technology that are brought in by schools where they've lost a sense of what they are educating for, so that they look for the technological expert to set the curriculum.

BROOKS: Then what is implied by what you say is that technology works best when it is introduced by pull rather than push, and that it is all right if it gets *pulled* into education, but it is bad if it gets *pushed* into education.

WEIZENBAUM: It is not necessarily all right in one case and not necessarily not all right in the other, although I think there is a greater chance that it will be beneficial in the pulling case than in the pushing case. At any rate, the Faustian bargain is very much invited in the pushing case, where it tends to be less so, it seems to me, in the pulling case.

DAVID: Do you think China essentially is making this mistake on a wider scale than just computers? This is exactly the experience the American Association for the Advancement of Science Board had in China. It's a case of tremendous technology push. How that is going to go down in a society like that is anybody's guess. It's going to be very interesting to watch it.

DAHL: Did you people express any doubts about that push to them?

DAVID: Yes, quite a few of us did, particularly some of the sociologists. The Chinese said, "We would like to try it and see."

HIRSCHMAN: One thing that was done in the OECD group, in which I participated, was to commission specific reports on technological progress in a variety of fields. There are available reports, based on impressions or interviews with people in industry, on technological progress in the last few years and expected new breakthroughs in, I think, four areas: machine tools, chemicals industry, computer electronics, and maybe textiles. There seems to be something of an agreement, although with some dissent, that there has been some stagnation in technology over the last five to ten years in most areas with, of course, the enormous exception of electronics, where there is an explosion of technical progress. There was also

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one point made in this connection by Christopher Freeman of Sussex. He feels that there is some stagnation in other areas, and that technology is very strongly limited to this field of computers and electronics in general. And, second, that which was called the perils of automation in the fifties was highly exaggerated then because this new industry still had to create its own infrastructure and create employment. It now has come to maturity. Then, like many times in the history of technology, what comes to maturity becomes labor-saving and poses a threat to employment, and is now ready to invade a great variety of areas. Thus applications are developing in a great variety of sectors including the services. So that the perils that were predicted in the fifties, but then did not materialize, may actually happen at this stage.

BROOKS: This may be a statement that is premature, but I find it very puzzling that in the United States the microcomputer revolution has probably proceeded further than in any other country: yet we have had less increase in labor productivity in the last five years than in any other similar period in our history. That could be only a temporary phenomenon, and the predictions that Chris Freeman makes could come to pass. It seems to me, however, that his arguments are unconvincing, because he simply looks within a given industry. In other words, he is maintaining that the computer industry is no longer creating employment by itself; but of course the technological revolution moves from one industry to another, and the relevant thing is not what happens within a given industry, but what happens in the rest of the economy. That seems to me a much more complex question than just looking at the labor intensity or the change in labor intensity of a particular industry. So I found the arguments Freeman makes moderately unconvincing. I can make convincing arguments on the other side.

VERNON: Harvey, the measurement problem runs a lot deeper than that. It is well to remember that we have got that nemesis of measurement, the index number problem, here. With the shift in the mix of demands in the United States, I do not know what you can say about productivity on the basis of either job-creating capabilities or any of the usual measures that are used, such as output per man. Suppose it were a fact, as it obviously is, that people want more health services and less of something else. If what they want at the margin does not lend itself to productivity increase to the same degree as what they are giving up, what can one say about productivity trends?

BROOKS: But even more than that, many of the things that people want are such that we do not even measure productivity. One of the things that certainly has increased faster than anything else in terms of employment is government services, and we simply measure productivity in government services by saying its increase is zero by definition, the way the index number is defined. But it may or may not be zero. We do not have any way of measuring it, so I think that just reinforces the case.

LANDES: Could be negative.

BROOKS: Yes! But it could also be positive—it still wouldn't be measured. There certainly is some indication that, if you use conventional measures of productivity at least, the medical care delivery system has a negative productivity

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increase because you do more things as technology advances, and there is no way of measuring whether the more things you do are really worth doing or not. We do not even have qualitative criteria for deciding whether they are worth doing or not.

E. MORISON: I can go a little further along the lines that I think Michael Maccoby was talking about. I have sympathy with what I think he was saying: that the organization of a technology depends to a certain extent upon the cultural surroundings it is put into.

MACCOBY: My experience in Sweden is that, culturally, a tremendous amount of hope has been invested in work as the form of human development, and it is more than the workplace can bear. In other words, many Swedes believe that other institutions will fall into place if somehow the technology of the workplace can be made to further a form of participation, development, creativity, when in fact you are in a culture where the arts and letters, the humanities, are deteriorating. And it is not working out. What is happening is just what you are saying: the people, those craftsmen, are not satisfied, and find their fulfillment instead in leisure, in escapist activities. I think this is another aspect of the issue.

VERNON: One aspect of technology that preoccupies me, of course, is the fact that technology, at least large areas of technology, until fairly recently, commonly could be related to some place, some space, some national boundaries. Stated a little differently, you could go onto the continent of Africa and observe that the relevant technologies being applied are different from those of Europe—those of France are indeed rather different from those of Germany—and that there was something called an American system of manufactures that reflected an approach to the production process that was a little different from that of Europe. That, of course, is rapidly becoming less and less the case. It's rapidly becoming less so in two very different senses. A firm like General Motors can contemplate the idea of a standard "world car," reflecting the fact that it thinks there is a mass market for the given product, the demand for which is not very different from one country to another all over the world, leading it in turn to think very differently about where it innovates, where it sets up production facilities, and so on. And in the very different sense that in some countries of the world—countries characteristically with lower levels of education and lower levels of income—different strata of technological application can sit physically together, sometimes creating intolerable stresses, sometimes creating remarkably little stress, but with enormous heterogeneity in any case. Perhaps there is a third aspect in which the separation of technology from a specific space is worth mentioning—the generation of technology in a particular area no longer guarantees, to anywhere the extent it once did, that the technology will in fact be applied primarily in that area. A group of us just turned over some data to the National Science Foundation, the collection of which they had financed, that showed really quite spectacularly the degree to which, for example, United States firms, having generated some new technologies in the United States, in fact were placing the production and output of those technologies abroad. The lag in time between the innovation in the United States and the placement of technology abroad has shrunk spectacularly in the past thirty years. In all this process, of course, the nation-states have not gone away. In many ways they certainly have the importance they had thirty years ago; perhaps more, as social demands on states have increased. You have the makings of a fascinating set of seeming inconsistencies—inconsistencies in the sense that no nation-state

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can any longer think of technological forces as originating, being applied, and having their consequences on its territory. It both must assume that technology generated on its territory will be applied elsewhere and that technologies generated elsewhere will be applied on its territory, in a setting in which it feels a need for the control of its own territory—I don't want to push this point any further than that. I just want to suggest, too, that playing the importance of the institution of the state against the universalization of technology leads you—leads me at least—to certain conclusions. One has the feeling that he's grasping at some important force without being utterly sure of what the consequences of the force are likely to be.

LANDES: I want to follow up on what Ray has been saying because I have followed Ray's work in this area for some time. He has, perhaps more than anyone, studied the way in which you get an internationalization of economic activity via enterprises that transcend national boundaries, but I think he'd be the first to say, as he's already in a sense hinted, that you have two forces playing here. You do still have desires on the part of national units to control things that happen within their boundaries. I would add that you also obviously have institutional arrangements in labor and elsewhere that affect the ability of these transnational organizations to introduce things; that some labor forces accept this kind of innovation from outside more easily than others. And I would add the fact that even here there are cultural considerations that shape the choice of places to do these things and the readiness with which places accept them. That is, in comparison with the past, it's clear that these parochial constraints are less important. There was a time, as Ray points out, when the choice of technical possibilities was, in fact, shaped in part by the national cultural context. It was no accident, for example, that it was the United States that first moved in the direction of manufacture of clocks and watches by interchangeable parts. And that was part of a larger American context. Similarly, I think it's no accident that certain kinds of changes in chemical manufacturing take place in the United States, and it takes the line it does by comparison with, say, the changes that are taking place in chemistry in a country like Germany. Those things were much more important in the past than now, but even now I think Ray would be the first to say that you really have a persistence of some of these old conditions and constraints, together with a new force; and I think the interplay of the two is of great interest, particularly if you also bring in the larger question of the disparity in technologies that still prevails between some parts of the world and other parts, and the whole process of diffusion. What do these two forces mean for the larger process of the diffusion of technology? We still have not reached a point where every place is, in a sense, operating on the same frontier with the same options.

HIRSCHMAN: I think it is very healthy to look at the cultural conditioning and consequences of technology, but I think one can overdo it. I think there is a tendency toward a guilt complex on the part of technologically advanced nations such as this one, and to say that it all depends on the culture. Actually, one outstanding fact about new inventions, and about certain types of inventions, is that they are so universally acceptable. This story begins, perhaps, with the invention of sugar, which became such a huge success, combined with disaster, of course, in early modern Europe. There are lots of stories of inhabitants of various slums in Latin American cities preferring television to a balanced diet for their children. The same goes for the motor car, contraceptive devices, and so on. There are some

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things that really respond to very basic urges or cravings that seem to take everything by storm. And the idea that a nation can adapt these things to its own needs, to its own culture, seems to me to be wrong. What happens, on the contrary, is that these things are being taken on, and then the conflict occurs. In other words, the idea that the new artifact can be adapted by the culture comes from a fallacious idea that we are able to optimize, to pick and choose. No, we are taken over, and then we have regret. In other words, later there is a reaction to it within the body social that will result in some sort of conflict, perhaps in explosion, perhaps in disaster. The whole idea today is assessment of technology, of side effects, and what are the negative ones, the benefits, costs, and so on, that come from a series of experiences with technology. Perhaps something ought to be said about the historical limits, about the intrinsic immanent limits of this sort of project.

LANDES: I want to follow up on this. First, I think we have to distinguish between the invention of a product and the production of it. It may well be that, for instance, television is the kind of thing that can be made everywhere. The kinds of cultural conditions that are conducive to the consumption of television may be very different from those that are conducive to the production of the instrument. That's the first thing, but even in regard to consumption, clearly, a great deal depends on culture. I had not known about sugar, although it is clear to me that cuisines vary in spite of the fact that sugar is available everywhere. I am sure that sugar consumption per head varies considerably from one society to another, even if you standardize for income. But, leaving that aside, I think again of the problems of time measurement, which I was speaking of earlier in connection with watches and clocks. The mechanical timepiece was invented in Western Europe and exported to other parts of the world beginning in the sixteenth century. They were as excited about these instruments as the people of Brazil are excited about television today, but they didn't understand their use as timepieces. They thought of them as very sophisticated toys. They paid large sums of money, those who could afford it, for a rather complicated and ornate instrument, but they did not use them the way they were used in the West. I think that is also a very crucial thing—you may have an interest in a given device that is very widespread, and yet different societies will put these devices to very different uses. I think that that is also something that you cannot overlook.

MACCOBY: One question that comes up in my mind is whether what we are trying to do is not to study technology, but to in a sense expand and develop the study of history, cultural change, political choice, human goals, to include technology. Really, the problem is that these subjects have not known how to deal with technology; and what we are seeing in this complexity is that it is not simple to deal with it from the point of view of history.

R. MORISON: I do not want to confuse myself too much with Hermann Goering, but I do feel uneasy sometimes at the premature introduction of culture into a conversation.

WINNER: There is one point I would like to make with respect to the issue of the autonomy of cultural values as opposed to the autonomy of technology. What we see very often in the social history of technological change is a rescheduling of values. The first time a particular device or system appears in a culture, there

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exists a certain latitude of choice that is never available again. Once the initial choice is made, the latitude of selectivity among a range of possibilities vanishes. The thing gets set in steel or concrete, and its use becomes an ingrained part of the habits of the culture. For that reason it is especially crucial to pay attention to the founding moment. From my own point of view as a political theorist, the building of technological systems is in many ways similar to the founding of political constitutions. One can talk about forms of order in politics and forms of order in technology using many of the same evaluative terms.

I think it is interesting to note that for a long while people did not find it very useful to develop the interpretive concepts that might be employed in the study of technology. The subject was not integrated into cultural theory of history in any significant way. Over the past ten or fifteen years, however, the situation has changed; the language of justification used in making decisions about technologies of various kinds is now "up for grabs." Simple homilies about "progress" or the exclusive use of criteria of economic efficiency will no longer suffice. Thus you have the appropriate technologists talking about systems on a human scale; you find people in urban neighborhoods rising up and saying, "No thanks, we don't want these highways going through here." In the professions, you find many people arguing that what appeared to be useful techniques and strategies haven't worked that well, for example, Peter Blake's criticisms of modern architecture in *Form Follows Fiasco*. Both insiders and outsiders are beginning to ask, "What are we doing here, and why?" and drawing upon a much richer set of concerns and concepts than they had previously.

SMITH: I have two comments. One is sort of a personal reflection on my field; the second is a suggestion about where to start addressing the problem at hand. One of the things that has bothered me as a historian of technology is that there are many scholars in the field who are reluctant to undertake what I call "integrated studies." What we need are people who can raise questions about technological development and look at it as both cultural manifestation and an evolving economic design. In a way I am reflecting on what has already been said about the importance of culture as a determinant of change. Such an approach is absolutely necessary in order to understand where we are today, how we got there, and how we might go about proposing agendas for the future.

How do you sufficiently define a problem that will satisfy all the different interests represented at this table? That is indeed a difficult question. A possible approach that comes to mind—one that follows from Professor Landes's remarks—is to focus on uniformity as a cultural force in Western civilization. The concept of uniformity embraces a large spectrum of political-economic issues related to the establishment of political *order*, technological *standardization*, and economic *control* in the modern era. As Langdon Winner's comments suggest, considerations of order, standardization, and control have defined, and continue to define, public policy decisions. In the case of the U.S. national armories, for example, the order-standardization-control triad was translated into public policy by the Army Ordnance Department, and out of that policy evolved a manufacturing system of interchangeable parts that eventually supplied much of the technical and management know-how to the U.S. automobile industry. There were other ways that the uniformity concept translated out through other industries—clocks, watches, sewing machines, bicycles, and so on. If Nathan Rosenberg were here today, he could tell you about the convergence of these technologies in the

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machine tool industry. Thomas P. Hughes could likewise verify similar trends in the electric power industry with its grid systems.

HOLTON: There is an infinite spectrum of possibilities before us with this topic. The most promising outcropping that I have seen is this constant reexamination that is now going on in our own new terms of "what is technology doing to us or for us?" In the 1930s there was a great debate that technology interferes with employability. That was a very interesting precursor of what I think is going to be a new discussion of that same sort as we go into this period of limits that Langdon has mentioned as the new era. The question, "What is it doing to us or for us?" is a very gut question to a lot of people in the United States, and there is a grand audience, not just our academic colleagues, looking for answers. What is it doing to the freedom of choice, to the human potential, including employment, to our freedom as a nation? The great Benjamin Franklin already previewed some of our problems when he said that the great thing about his so-called Philadelphia stove was that it would allow us to depend no longer on foreign imports of coal, but on our native American forests, and that this would free us from any future dependency on those Europeans. What dependence on technology is doing to our freedoms is one of the main themes that I see. I think that is where the battle is being fought out. I do not quite see how to do this, but the appealing thing is to look around for one among many candidates. To take the most difficult problem in the mind of the public, there is the arms race. Technology and the arms race are the polarities there. On the one hand, the increase in the balance of terror is fueled very systematically; on the other hand, inspection possibilities through technology are now available. This problem prevented the treaty with the Russians some years ago, when outside inspection had to be insisted on because there was no technology for monitoring the tests with any credible certainty. So there is a polarity of that sort.

MACCOBY: I think the very important point to bring up about education and technology is how poor the presentation of complex issues is on technological questions. I think that is absolutely crucial, but I do not know what can be done about it.

BROOKS: Perhaps the biggest revolution of all that has occurred in the last generation is the organized generation of technology and the creation of institutions to manufacture technology, almost in the same way that in the nineteenth century we created the institutions to manufacture goods. This surely also must have some impact on the way technology affects society. To come back to the question of the definition of technology, there is the obvious issue of whether we are talking about simply hardware. I think it becomes increasingly difficult today to talk about technology as hardware because the boundary between hardware and software is becoming fuzzier and fuzzier. By software I mean not only software in the conventional sense that is used in connection with computers, but also management science, operations research, organization theory, and the applications of those things. One way of defining technology is as a reproducible and publicly communicable way of doing things. This, then, includes the social dimension, but excludes a great deal of perhaps intuitive approaches to social problems. Nevertheless, it is very difficult to draw the line between the reproducible and publicly communicable, and the more intuitive, because even public communica-

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tion requires a large degree of common framework. Some of the difficulties, it seems to me, in discussing the communication and diffusion of technology, really have to do with this question of the framework within which communication takes place. You simply have to have an intellectual structure in the recipient before you can communicate very much to him.

MACCOBY: I know. For example, the questions are good questions: How far is technological development autonomous? How much is it developed by a particular power structure for a class interest? How much is it in demand from a population? These are good questions that can only be answered within a cultural context. Let me illustrate. I once wrote an essay called "Who Creates New Technology and Why?" In looking at a lot of the industrial technology that was developed, particularly in the electronics industry, I was trying to pinpoint exactly what was developed and why. I was struck, going into companies like I.B.M. and interviewing people in R&D, by how many inventions were never developed and produced, and by why some were. It is complex, but it comes out that technology is developed as a response to two basic factors. One is a market mechanism that wants things that increase predictability and control. New electronic technology is sold to other companies or government bureaucracies, which buy it because they believe it will increase predictability and control. The other type of technological development is determined by governments, in terms of national security. When you look at the variables that determine national security, they have to do with issues such as glory, power, and protection, all of which are limitless, consistent with Albert's thesis. Perhaps these same factors operate in the demand for medical technology. There are no limits to how much national security is enough, and there are no limits to how much glory is enough. There are limits to market mechanisms and what actually increases productivity or control and predictability. Those things, though, are culturally determined and cannot be looked at as separate from a particular society or culture, world view, market system, national security apparatus. To approach the system just from the point of view of whether a small group creates technology, ignores that it is only understandable within this whole complex fabric of our market-national security society. In making those distinctions, one begins to see what difference it would make to control the national security part of it in terms of the possibilities of improving the market part of it, and so on. I do not see an inconsistency, but I do insist that, unless one starts from those issues, one gets into mystification, and it all becomes very abstract; that is what has been happening. It seems to me that we have never integrated technology into these other fields in the way that it deserves to be. To go back to sugar—sugar is fascinating—the relation of sugar to social organization has often been critical. The development of sugar was a key, perhaps *the* key, element of the Mexican revolution. If it had not been for the nineteenth century haciendas—with a demand for sugar developing a new technology of sugar refining with a centrifugal system, plus the infrastructure of railroads and so forth—there would not have been the demand to take away land from the people, who had it for generations, in order to build up large hacienda systems to mass produce sugar, and, in that case, you would not have had those small peasants turning to Zapata to protect them from encroachment by the national government based on sugar. I think to look at that issue either as a pure technology issue or as a pure history issue misses the fact that we need to integrate the importance of technology into our total historical understanding.

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GRAUBARD: Just to keep you one more minute. You talk about increasing predictability and control, and at one moment you suddenly also introduce the increase in productivity. You unwittingly added the word, or perhaps wittingly.

MACCOBY: I think people have believed that increasing predictability and control does lead inevitably to productivity. We are only beginning to question that now, but I think it is not necessarily the case that increasing predictability and control in the sense that technology has been thought to do, certainly since Frederick Winslow Taylor, will always increase productivity. Organizations buy technology, like computers, less because they really can prove that they increase productivity than because they are convinced it increases predictability and control.

GRAUBARD: You introduced the word productivity, and I just wanted to make sure it was not an accident.

WEIZENBAUM: I just want to pose a couple of questions to Langdon Winner stimulated by what you have said. Langdon said that when technology first is introduced, the latitude is greatest, the number of degrees of freedom is greatest, limitations appear only later. Of course, you first enter an empty space, so to speak, and this is where I want to touch on the question of technology being introduced in response to market mechanism.

BROOKS: I think it is very true that technology is not demanded by the market. The market really does not demand anything that does not exist, and so the market really only begins to act after the technology exists. Most of even the radical technologies that you think about were originally generated as apparently minor improvements on something that already existed. After all, the automobile was first a horseless carriage, and it was only way down the line that it began to create its own market.

CHANDLER: There are many examples of need inducing innovation. Oil was around all over the place. Yet, not until whale oil had run out and artificial light was needed in the rapidly growing cities, was it turned into kerosene. Then the technology of refining developed quickly. Clearly the train, or the locomotive, was needed. People were working on it besides Stephenson. The cotton gin was the greatest example of an induced invention—everybody and his brother were working on it in the early 1790s. The cotton gin could not have come ten years earlier, because new English textile machinery developed the need for cotton; but it hardly could have come much later. One technology required the development of others. Certainly, the development of the telegraph was essential to the running of a railroad. You could not run an airline without modern communications. I can list a set of innovations that happened in the 1880s that could only come—a very minor one was the mass production of cigarettes—once the railroad was laid down, although not everybody in the 1880s began to move into mass production.

MACCOBY: But the market gives a framework in which people start to try to develop something. If labor is expensive, that is already a market mechanism that is pulling a lot of people in certain directions. It is already causing a selective process in a culture that would not exist in another culture where labor was very cheap.

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BROOKS: I like to use the analogy of biological evolution: that in fact the environment creates stresses in the biological system, but it is a genetic variation, analogous to the invention of technology, that in fact produces the structures that then can be selected by the environment. I think that is the way the market as well as the political structure act on technology. The generation of technology tends to be semiautonomous, and it is only when it begins to emerge that environmental pressures act on it and select which technologies actually get developed and which ones die at a very early stage.

DAVID: I think you ought to try to answer the question now that you raised earlier, Harvey. What do we think technology is really going to be in the years ahead, its role, in terms of culture? Does it have a central role, or is it entirely subservient to national and international purposes?

BROOKS: Well, I am not sure that those are alternatives. You presented the question as though those were mutually exclusive alternatives. I would argue the fact they are the same thing. I think it has to be responsive to national and international needs, but in fact those needs cannot be responded to without technology.

MACCOBY: In part they have been created by technology.

BROOKS: Yes. As a consequence of the spread of technology.

MACCOBY: The history of needs is another aspect of the pull-push problem. What is a need?

DAVID: I thought you were saying something different. I thought you were saying that, in the process of trying to invent and create technology for markets, you really cannot predict what the markets are going to be, because the latent markets are not foreseen, and, therefore, in this process you produce a technology that has its own driving force and that develops these new markets. It seems to me that is, to some extent at least, a primary force rather than a secondary force of the culture.

BROOKS: But that statement is true in the same sense that it is really impossible to foresee the course of biological evolution by just looking at the environmental stresses acting on species. It is relatively easy to invent *post hoc* explanations of why certain species' characteristics evolved out of the environment, but I think it is almost impossible to predict ahead of time what the environmental stress will bring forth in the way of biological evolution. I think you can say a somewhat analogous thing about the evolution of technology. It is very easy to understand in retrospect why, let's say, the computer or the automobile or various other technologies evolved as they did in response to social stresses represented by the market and a lot of other factors, to make a *post hoc* explanation, but it would have been very hard to make a prediction ahead of time, because, in fact, the particular course of events was not uniquely determined; there was a lot of randomness along the way.

DAVID: You said earlier that you thought there was a question of the role of technology in the current *problematique*. What is that role? It seems to me that you are getting at that question.

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BROOKS: Yes. I do not see how, in fact, the world can get out of its present *problematique*, or at least resolve it without catastrophic changes, unless there is a tremendous amount of assistance from technology. That does not mean that technology can solve our problems, but only that our problems cannot be solved without new technology.

DAVID: You have to go one step further, perhaps, and say that there has to be some level of freedom in the development of technology, or else it will be so constrained, that you will not get these great excursions that really provide the new versions in which, if the problem cannot be solved, it can actually be bypassed or made less important. Would you agree with that?

MACCOBY: You say that certainly freedom is necessary, but the issue is, how much. Would you say you can address this *problematique* with total freedom, or do you have to have some controlling constraints: are there some central directions; what is the relation between freedom and authority in addressing the issue of the role of technology in answering the *problematique?*

BROOKS: My answer would be that it really has to be geared in a very complicated way to its closeness to application. Clearly, you cannot have complete freedom all the way along the line, but if you do not have a large amount of freedom at the beginning of the process, you have the situation that would exist in biological evolution if genetic variations and the random combination of genes did not exist. So you have to have, in the early stages of technology generation, something analogous to what sexual reproduction creates in the biological system. Yet that cannot go on indefinitely, if only because you cannot develop every idea. It is when you begin to narrow down the process that you put on constraints, and the question then is, what will be the nature of those constraints, and how will society respond to them. Are you letting those constraints be set entirely by the market; do you let them be set by some kind of a political process; and if so, what is that political process and who participates in it, and what legitimizes that participation?

DAVID: You know, from the industrial side, I think you have put your finger on perhaps the critical issue that we see in industry today.

HIRSCHMAN: Carl Djerassi has been very eloquent in this particular area, regarding the time it takes to develop a technology today. With the controls we have, it has been said, we would not come up with aspirin, or aspirin could not be marketed. So this is important—the whole issue of these controls and the dangers of saying yes, but also the dangers of saying no.

BROOKS: I think there is another aspect that needs to be brought up. We know that in biological evolution there are dead ends. It seems to me that the same process that produces dead ends in biological evolution can very well produce dead ends in technological evolution, and the questions are: To what extent can we avoid those dead ends, and by what process? How can we recognize them?

HOLTON: You would also probably add a "time-scale mismatch"; that is, there must be some kind of a natural relaxation time for technological innovation and another time scale, a natural scale, for the funding, owing, for example, to mon-

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itoring the impact and the legal controls. If we had ten-year funding, we would have very different technologies.

BROOKS: But there is another process that occurs. Somebody spoke about the great amount of freedom that existed at the early stages of technology. This tends to narrow down, and you only have to look at the history of inventions like the automobile or the computer, where you go through a stage in which a thousand flowers bloom, or whatever the expression is. You had twenty-five or thirty automobile companies producing all kinds of variations on the basic theme. That very soon narrows down to Alfred P. Sloan's concept of the annual style change. Almost every technology tends to go through that kind of history, and the automobile case, I think, is an interesting one, because, apparently, the shock of the emissions and safety laws of the 1970s had a fairly profound effect on the automobile industry. It increased its real investment in research by something like 25 or 30 percent over five years. I do not know how different an industry it is, but it certainly is quite different from what it was in the 1960s.

GRAUBARD: I do not know how Burton Klein's dynamic economics is viewed, but this is one of the examples he uses in great detail.

MACCOBY: I am somewhat troubled by Harvey's biological analogy, even though I like it. I am worried about its molding our thoughts in such a way that we lose important distinctions. It seems to me that there is a big difference between a species and a whole technological system that makes a really significant difference in our culture. For example, to talk about varieties of cars is the wrong path, because the car plus highway system plus petroleum and all its developments—I mean the car as a technological system—is really what is interesting historically. It is something that starts out as a horseless carriage and becomes a total system, including rubber plantations, a form of unionization, and so on—a whole system.

BROOKS: But all this happens in biological evolution, too. You know, you get species occupying closely related niches so that they are mutually dependent, and that, in fact, greatly constrains the further evolution of the system. So I think the same thing happens very often in biology.

HOLTON: Harvey, he may be talking about a condition that just is not accommodated in that biological metaphor. To exaggerate what he's saying, it's like encountering a rather pleasant little dwarf, but at a certain point it turns into the dragon Fafnir. It changes from one organism into another, with a very different property, rather suddenly.

E. MORISON: This happens all the time in insects.

MACCOBY: I think if you put it that way, that is satisfying. I think it is worrisome if it is not seen in its systematic point. Like the development of man. That is not just development as a species, that is a change in the plot.

BROOKS: That is also true of technology. But I think we have then to start to make that kind of taxonomy, and a selection among changes, or else we miss some of the really important questions of what types of technology become generating technologies that proliferate ancillary and related technologies.

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E. MORISON: Having found out what the argument is about, I would like now to see if I can find out where it is leading. If it is technological generation, which it seems to me to be, it seems to me also that Al Chandler gave a very nice description of that process in the 1880s, working within two constraints: the state of the market and the state of the art. You have interactions going on that were pretty well determined by those two things, but it seemed to me that Dr. David, in asking Harvey his questions, was asking if that process has now reached a point where we might require more self-conscious and applied constraints. If so, what kind of criteria do we use to make up our mind about that?

BROOKS: Before, we let the market largely set the constraints. Now, there are obviously a lot of other ways to set constraints and the question is, which ones.

E. MORISON: It seems to me that these are very interesting questions. If I followed the line of argument, we backed away from these and led back into a description of the process as it has been, rather than searching around for possible criteria and possible innovations to order this developing structure.

BROOKS: Well, part of the problem is that we tended to approach it in an asymmetrical way. That is, we have suddenly pushed very strongly for constraints on the development of technology because we have recognized the adverse effects of no social constraints. Yet, we have tended to forget that the process is probably much more symmetrical, that is to say, that the inhibition of technological development can have just as many adverse secondary consequences as the promotion of technological development. We have not arrived at a way of balancing these two questions. If you cut off the development of a particular technology, you usually generate pressures for the use of other technologies, which in fact may be worse in their effect than the technology you cut off.

MACCOBY: Could you give an example of that?

BROOKS: A somewhat trivial example was the move to ban phosphates; immediately, the companies introduced nitrogen-containing phosphates that proceeded to poison children. The famous fireproof sleepware is another case. The early introduction of air pollution regulations in the late 1960s opened up the uncontrolled strip-mining of western coal, and probably produced a lot more adverse environmental effects than the air pollution that was prevented by using low sulfur coal.

HIRSCHMAN: I think that these undesirable consequences you mention specifically do not exhaust the possibilities. The main reason that people are against controls, against certain excessive controls, is simply that they shut off possible beneficial effects that may come in due course and that cannot be foreseen. In this connection, something sticks in my mind about the effect of technology on basic science—as a result of the interaction between new products, new gadgets, and nature. This interaction often led to important new advances in basic science, as the steam engine led to advances of thermodynamics. In fact, one of the reasons for the cumulative advance of the small group of industrial countries can be explained in this manner, I think. The new gadgets are first coming into mass use in these countries, and this gives them the chance to observe the interaction between these gadgets and nature, and therefore a basis is laid for further advance in basic science, which in turn leads to further applications, and so on.

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E. MORISON: I am uneasy about the course of this argument, and I think I know why. If one says that the time is coming near when we must think more self-consciously of constraints, and we think of political ones, or, in the analogy of biology, that kind of process, or just the managerial skills involved, I do not think that is going to be enough. We need some surer sense of the base of operations that we are working on. That is what Huxley said at the dedication of Johns Hopkins; that he really did not care how powerful America was in terms of iron, coal, steel, and all that, the essential question is, what you are going to do with these things. This brings me back to the cultural theme that we began with. It seems to me that we cannot use any of these constraints effectively—managerial, political, or economic—until there is a larger cultural agreement than we now have on the scheme that we want to use all these things for. That introduces a rather complicated set of considerations, but I have no hope that we will manage trying to deal with them.

MACCOBY: From this point of view, what do you see as desirable—if we could control technology, if technology were really intentional—what would you see as the desirable values that would determine technological development? Not exactly the same as the World Bank is using, but along the same lines. Another might be the respectful control of nature—ecosystems, weather, catastrophes, disasters. A third might be spirit of adventure in discovery and understanding of the universe. Another, the goal of human dignity, which also has to do with the nature of work and education.

BROOKS: There is a problem, of course, and that is, when we look to past societies with well-developed value systems, in many cases they were value systems that had a certain coherence for a certain size group, but were not value systems that were viable in a larger size group; they were value systems that often were in opposition to other groups. To look to the value systems of the past is simply not a valid way to approach the problem any longer. We have to look to a value system that embraces all of humanity in some way, and that is a very much more difficult problem.

E. MORISON: And those past value systems were frequently designed to enable you to put up with things you couldn't do anything about. Here our problem is to figure out how to do all the things we can do in a way that makes sense.

HIRSCHMAN: There is one point in my mind in connection with technology and its dangers. The assessment of technology and control of technology was, I think, easier in past periods for two reasons. First, because, traditionally, you had one generation willing to try out any kind of medicine, means of transportation, or other technology—to be a guinea pig for the next generation. It was generally not realized, but, in effect, we behaved that way, accepting dangers or risks of the technology because the promise was such that the first generation was willing to bear those risks in the assurance that those risks could later be eliminated or at least substantially narrowed. In time, you come up against those difficulties, whatever they might be, but you have to experience those difficulties in order to solve them. You can't solve them all ahead of time; sometimes you did not even perceive them ahead of time. I have called this phenomenon "the hiding hand." That was one sort of assurance that we used to have, and I think we no longer quite have it. Because of certain types of new technologies, with consequences such as radiation, we really feel we have to control these things from the outset.

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The other new difficulty is precisely the rapid diffusion of new technology. Previously, things were compartmentalized. In fact, if a technology developed by one particular culture, country, continent even, yielded very bad results, that country would suffer, and others would take over, and you would have a displacement of power since you did not have rapid communication. In a sense, today we have a double-edged situation.

The third element of difficulty appears when we compare technological advance with social innovation. With new social devices we often have the possibility of experimenting. The best method to find out if a social innovation is O.K. or not—since you cannot predict all the positive or negative consequences from the start—is to apply it as an experiment, to use it in a small area, such as using a county to try out a negative income tax, or school vouchers in order to find out how they do really work. These are new ideas of social policy, and, generally, it will be found acceptable to experiment with them. Imagine, though, what it would be like to introduce a new, risky contraceptive device just in one place, which was in fact done with Puerto Rican women at one time. It really is now socially unacceptable to handle matters that way. Why is it unacceptable with technological devices and not with social or political devices?

BROOKS: One of the difficulties with this approach, though, is the fact that many of the adverse effects of technology are associated with *scale*. Therefore, you don't really find out about them until they are applied. For example, automobile pollution was not something that was of any significance until you had automobiles on a vast scale, except in Los Angeles County, where it came a little bit earlier.

HOLTON: To follow up on the other two, part of what you said, and something that I've often thought about, is the briefer and briefer time scale between the time a technology is introduced and the time that it has become very widely diffused. That has threshold effect. Up to a certain point you can have a democratic process of informal technology assessment. But when it gets so short that the informal process no longer works, then we are beyond this kind of assessment. It took from the 1830s to 1900 to let the electric motor invented by Faraday change the scale of cities by subways and elevators being introduced. One could imagine nowadays cases where, within a few years, a large new technology changes habits and behavior on a very large scale. And, at that point, the feedback system no longer works for modification of the less fortunate parts of that innovation. So I think one may be able to document the changing time scale and what intervenes when these time scales get beyond a certain critical threshold.

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BROOKS: I guess my real interest in this is the future and what the future role of technology is, not only in the West but in the world. And to what degree can one, in fact, direct the future of technology for solving the problems that we think are the most important. It's partly the point that Elting made, but I look at it more positively. I think the positive is more important than the negative in a certain sense. The question is not so much how we limit technology, as how, in fact, we direct it, channel it in the most constructive ways. Is there any mechanism by

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which one can arrive at a sensible consensus, and if one arrives at such a consensus, how does it get implemented?

E. MORISON: I think we share the same exuberance about the possibility. I am unhappy that technology has come to be looked upon as a problem. I think that it offers opportunities far more interesting than in any previous period, if we could figure out how to manage it.

BROOKS: Exactly. In fact, my sense is that the promise, in a certain sense, is much greater than it has ever been, but so of course are the tasks undertaken, and they have a very large social dimension. That is why it is so difficult to deal with. I'm not envisioning a gigantic technological fix, and I think that is what makes the problem unfamiliar. But technology is an absolutely necessary part of the solution, though perhaps only a very small part. That's really the issue we're dealing with. Technology is necessary, but not sufficient; and it may be the most necessary part, but it's probably only 20 percent at most.

DAVID: Managing the uses of technology is one thing, but managing the processes that produce technology is a worrisome prospect. We almost end up saying that the technologists or the managers or the scientists—whoever it is that produces the technology—are the intermediaries between the public and the shrine. As researchers, we have to be awfully careful that we don't, in the process of proposing to manage technology for the good of society, relinquish our control over the processes that produce technology at the same time. I think that would be a disaster.

BROOKS: Yes, but I think those are mutually incompatible. That is, I don't believe you can manage the processes without intending control over them. I don't think that the society can completely take over the management of technology. One of the problems with the present period is that society is trying to take over the detailed management of technology. The problem is how society can participate in the management of technology without wrecking it.

MACCOBY: I think that whole part of the subject is very little addressed. Due to the kinds of things that you're talking about, the mode of achievement is not neutral. It may be necessary to have participative design to work these things out, even if they are going to be achieved. Just to give a simple illustration: to set up a food technology that helps basic human needs can be devastating to a culture. As we find in pastoral societies like the Fulani in Africa, if you break up the ecology of farming and grazing, even by making the wells deeper, you can destroy that. You can't separate that kind of technology from the process by which it develops: the kinds of limits that are built into the political process versus the freedom that is allowed within those limits. All of those things are not irrelevant to technological goals and have to be included within them.

ROSENBLITH: May I go back to a more general issue. Technology seems to be one of the major experiments of the human race; it has had a kind of influence on the way in which humanity is evolving that very few other "natural" variables have had. We see an enormous number of local experiments. Different cultures, different subcultures, different countries, different ideologies, engage technology in a

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given historical context: they all become technologized but in often quite different ways. We do not understand very well what the technologizing of the professions is doing to them today. In some ways the university is most closely connected to that educational process and yet has very little understanding of what the technologizing is doing; not only what kind of a new division of labor is occurring, but also what kind of a new division of knowledge is occurring. Were we to look at these issues more closely, we would find that what is "system" to one profession could be "component" to another. Under these circumstances, the role that various technological elements play for the various professions, the various publics, is not invariant. Let us take, for example, the way in which women relate to technology. The great labor revolution that is taking place in many countries derives in part from the fact that technology has changed the role of women enormously and brought many of them into the labor market in a rather different way from before. When I was in engineering school I was always told that a good engineer asked what the "specs" are before designing anything. But here we are talking about "specs" at very different levels from the "specs" for a given piece of hardware. We are talking about "specs" at the level of hardware systems and of software systems. Anyone who is involved in problems of technology transfer from one society to another realizes very quickly that neither the "specs" nor the context for the "specs" is firm. Under those circumstances, technology transfer has remained a puzzle in our relations with many different countries. I spent last Saturday morning with people from the Academy of Social Sciences of the Peoples Republic of China. The question was how they can transfer our technology and not get into the same quagmire that we have gotten into. That was the way the question was formulated by the visitors. They would like to take "pure" technology and transplant it without getting an immune reaction to it. That is part of the unique role that technology is playing in hunan experience that cannot be captured by settling on a given social paradigm. You have to take a variety of social paradigms in order to explore what the "nature" of technology does to human society and to human individual experience. It is not simply a question in which we can take a given set of technological puzzles and then try to solve them in a given social setting or a given subculture and for a given period in history. The problem is that the more technologically developed, the more levels of technology we have. For the public at large, the nonprofessional public, this is a very difficult thing to grasp. They would like to be able to deal with one level of technology. So would each profession: "If you just take as given a particular kind of technology, I will hire you as a consultant. The rest I will decide." The medical profession is probably the most outspoken in that respect and has traditionally been operating that way. In a society that is becoming as highly technologized as ours, this is, however, not the end of the expertise problem. Under those circumstances we maybe ought to spend a little time to understand the education of the professional elites and what technologizing does to them separately and to their relationship with each other.

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MACCOBY: We are at a time where there are great positive possibilities of people working for common purposes. There are also great negative possibilities. We hear a lot about the popularity of Christopher Lasch's book on narcissism in America, a pessimism that is very fashionable. I think, however, that while those possibilities of egocentrism and narcissism are there, qualities of leadership can bring out the opposite. In other words, the same people who could become egocentrically ca-

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reerist oriented can be brought to a spirit that transcends egocentric interest and is concerned with goals beyond—that have to do with interdependence and human development—and they can respond in a way that I do not think would have happened a generation ago. In other words, the volatility in the American character right now seems to be tremendous and makes the role of leadership absolutely crucial. If you go back and read William James on pragmatism, what he said was that truth would be discovered neither by the tough-minded people who live by numbers nor the tender-minded who live by ideology, but rather by people who make their ideals explicit, are willing to test them out and experiment with them constantly in the real world. That was really the essence of the American experiment. The strength of the country was in that approach to development, and I think that is the kind of approach that is implicit in everything we have been talking about now; the kind of pragmatic development of technology based on a clarity of values and an experimental attitude to everything that has been taken for granted, which by its nature transforms the role of the expert. In that context you can also compare it with Japan or other countries that are very different and have a very different spirit, though I do not think any of those countries by themselves are going to deal with the global issues of responding to needs of survival and dignity as we can.

HIRSCHMAN: I want to connect the idea of a comparative study to Michael's remarks about possibilities in leading countries. There seems to be some potential conflict here because the possibilities of a leading country or countries may be somewhat different from those of other countries—countries with the possibility of going along or refusing or adapting. Countries that are not leading countries may have degrees of freedom that are not those of the leading countries. From an economic point of view, certainly, that seems to be immediately the case when one thinks of theories such as Vernon's cycle. A country may owe its position in international trade to the fact that it constantly develops new products that for a while it will export; and then other countries take over those products. That schema of the international division of labor seemed at one point to be a better model to represent what is going on in international trade than the traditional Ricardian specialization model, in view of rapid technological progress and its diffusion to other countries that follow at some, hopefully respectful, distance from the leader. In that situation, obviously, it would be harder for a leading country to adopt some self-restraint, or some control of technology, because its very comparative advantage, its very position in international trade, depends on being progressive all the time. There are problems here that I think are really specific to the leading country or countries in terms of regulation. I largely agree with Michael about the consciousness of these problems, although you find people in this country and others who are also conscious of the *problematique*. Somebody said that this country always has to be at the head of everything, because, even in such problems as narcotics and drugs, it outdoes all other countries in respect to the intensity with which it lives these problems—at least we are still ahead of the others in that sense—and that also applies to the new mood of rebelling against technology. We also seem to have outdone all others—although I do not know who has the best demonstrations—in opposition to nuclear energy.

E. MORISON: Taking the possible direction proposed by Harvey Brooks, that we really worry about the ordering of technological development of the future, seems to me to be the central problem of interest. I would ask those who have

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supported comparative studies what you would get out of these that would assist you in thinking about that problem. It is clear that you would get some arresting things, and that there would be lots of cultural solutions of different kinds and different kinds of gadgets. But would they really deal, or could they be made to deal, in a way that would enable us to think more imaginatively about what Walter has called our experimental situation.

GRAUBARD: Harvey touched on a series of questions, and he kept asking how *do* we direct technology, how can we reach some consensus on where we want to go? It is too bad that technology has become a problem, yet the promise for us is greater than it has ever been before. Who is the "we" and who is the "us"? We have been dealing in this early part of the afternoon with a whole set of political problems without making any distinctions, as if there is something, a kind of collectivity, called the American nation. I myself found it a little unsettling to feel that we were quite so much the hope of the world in all this as I heard, but this may be my own greater skepticism. Still, I am a little worried about this because I think it is very relevant to who the "we" is that Harvey is talking about.

WEIZENBAUM: Let me just underline that by calling your attention to a film that you may or may not have seen on the Nova series—the film on computers called *The Mind Machines*. At the end they showed an electroencephalogram device in which the computer acted as nothing more than an electronic filter. The claim was made in this prestigious science show, probably the most prestigious science show in America on television, that "the computer is reading this lady's mind." The program was chaired by Arthur C. Clark who said that, if we are lucky, these computers will keep us as pets, and ended by saying—

GRAUBARD: What if we are unlucky?

WEIZENBAUM: That is right, that is what it was about. He ended by saying, if that happens, it will serve us right. I reacted strongly to the word "us." Who is this "us"? The point is that there are in a few laboratories of the world a handful of people, let me exaggerate the number and say a hundred, working on things that could have incredibly harmful consequences. Presumably no one wishes for these foreseeable disasters to occur. But if they occur nevertheless, "it will serve *us* right." I think people generally, ordinary people walking around out on the street, the people who saw that film, have a right to ask, "What do you mean, it will serve *me* right? What have I done?" I think that is a terribly important question.

HIRSCHMAN: Every country has the technology it deserves.

WEIZENBAUM: I don't think countries deserve things any more than peoples do, especially things that are imposed on them by others.

LANDES: My sense of that kind of thing is that it is just another version of an old theme of Western culture. It is the theme that runs alongside the one about the unlimited possibilities of men. This is the reverse theme, that we are playing with very dangerous forces, that all kinds of unhappy consequences may eventuate. When he says we will have deserved it, what he is saying is, "I am putting you on notice now that this is dangerous stuff, and if we do not do something about it now, we may pay for it later." I think that is essentially the same notion of hubris.

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WEIZENBAUM: Wait! Let us hear what you just said. You say, if we do not do something about it now, we may have to pay for it later. What I have tried to underline here is what you have just said. The most generous interpretation of Clark's statement is that it is a warning. If that is correct, then he is not being hubristic himself. But that raises the question, what ought the people out there whom "it will serve right" if they do not do anything—what ought they to do?

LANDES: They should join the Clamshell Alliance, and they should set up bans on genetic experiments. Essentially, that is the warning. He definitely seems to be hinting at that.

WEIZENBAUM: It is a question that is in the air, and if we here, or others, do not come to grips with it, it will remain floating, until one day it will come down with a vengeance. Well, this is the real question, as I listen to some of the discussions this afternoon: the term of public accountability. We have gotten into a jargon in respect to a number of these issues, but I wonder whether one of our purposes is to—I hate to use the word—"dejargonize" our own thinking. I think that could be a very useful purpose.

E. MORISON: Steve, I think when Harvey says "we," he means that every human being is part today of a situation that no one knows very fully how to handle, and collectively "we" end up in a jam. Collectively, we ought to think about working at it. I do not think he is just saying that there are certain people who know more than others. He has got a kind of Old Testament view that we are all, if not sinners, ignorant in the hands of an angry machine.

WEIZENBAUM: I would like to add one thought, stimulated by these remarks. Robert Morison started out by saying that, as a scientist and a technologist, he was very uncomfortable with questions like this, because he was taught not to ask what these things are for. But you are a physician, and as a physician, surely, you were taught what to do if a patient were to walk into your office and say, "Doctor, I want you to amputate my little finger, and how much do you charge for that?" You would not do what the technologist does, that is, ask, as was said earlier, "What are the specifications? Do I have the resources? Do I have the competence?" and if all these questions are answered appropriately, say that you will perform the amputation. Instead, you take that responsibility for finding as best you can what the problem is. You may decide that what is really necessary is aspirin or bedrest, or an amputation of the foot, and you will behave accordingly, quite independent of how much the patient is willing to pay you to cut off his little finger. That is what you were taught as a physician. That is precisely the opposite of what happens in almost all engineering practice. In engineering practice, in technology, the technologist is asked to build a bridge across this river, to build a building, and so tall. The technologist then asks whether the task is feasible: for example, is the ground on which the building is to be built sufficiently stable; are the financial resources there; is enough time allowed; are there conflicting regulations from the Federal Aviation Administration? If no such difficulties exist, he says, "Very well, I will build you that building." It is not asked: Is this a good thing for society? What is the problem? Why does that building need to be built?

R. MORISON: Can I make an attempt to comment? The way physicians look at their responsibilities is not as simple as you make it out, and it is not the same now

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as it was when I was in medical school. Nowadays, for example, the business of prolonging life is a matter of very great discussion. The question of how much one uses one's own value system to decide what to do, and how much one should refer to the patient's value system, has changed a great deal. There is much more in the literature, there is much more discussion in ethical circles, about putting up to the patients the choice as to whether or not to have a radical mastectomy or take a possible slightly larger chance of recurrence by having the less radical one.

* * *

GRAUBARD: We have raised an enormous number of questions in these last hours. I have the sense that when we transcribe these remarks we may decide we want to share at least a certain number of them with our *Daedalus* readers. That, in any case, ought to be one of the options we consider for the issue we are planning, since our purpose, quite simply, is to acknowledge that new questions about technology need to be aired. With this, as with so many other issues, we have been too modest in accepting a traditional agenda of discussible items. We need to go beyond where the mass media are prepared to take us, opening up wholly new areas of inquiry. No one can underestimate the difficulty of that task; it would be difficult, however, to exaggerate its necessity.

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N. BRUCE HANNAY AND ROBERT E. MCGINN

The Anatomy of Modern Technology: Prolegomenon to an Improved Public Policy for the Social Management of Technology

FOR ALMOST TWO CENTURIES TECHNOLOGY HAS ALTERED the contours of modern life in the West. This pervasive influence shows no sign of abating. On the contrary, whether in terms of its impact on the natural environment, its contribution to the transformation of social and political relations, the changes it has wrought in the fabric of everyday life (in patterns of work and leisure), or its effects on modern consciousness, technology's impact on modern life has been profound, and promises to be of even greater import in the future.

In the last two decades, awareness of the triumphs of modern technology has begun to be informed by desire to tailor technology more precisely to perceived needs and apprehension over a variety of problems associated with modern technological innovation. Faced with innumerable problems that would seem amenable to technological solutions, society wonders why these cannot be found more rapidly. And, fueled by anxiety over pollution, the arms race, and nuclear power, concern over the effects of technology has reached a point where the question "Do we need better controls over technology?" is no longer one of merely academic interest but an important item on the agenda for public debate and action. Differences of opinion on these complex questions notwithstanding, there is widespread agreement on two general points. First, it is now imperative that technology be prudently utilized and effectively controlled by society, and, second, modern Western society has been less successful in foreseeing and avoiding social problems arising from its technology than it has been in bringing into being a remarkably complex and powerful technological order, one whose fruits are widely enjoyed and largely taken for granted. There are, however, signs that in recent years the United States has taken its first fledgling steps toward developing a revised set of institutional response mechanisms aimed at improving society's ability to cope with problems arising from its expanding technological capacity.

Whatever mechanisms are introduced must be based on a comprehensive and sound understanding of the nature and ramifications of technology, in particular, of technology in its distinctively modern guise. That is to say, many problems posed by technology in contemporary society derive not from the nature of technology *per se* but from the specific character technology has assumed in modern Western society. Herein lies the purpose of this essay: to

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describe and assess the significance of modern technology in a variety of its noteworthy facets, distinguishing those characteristic of technology *per se* from those unique to modern or contemporary technology. Our objective is to generate a comprehensive agenda of concerns to be taken into account in formulating a policy for the social management of technology that is adequate to technology's complex, changing nature and its profound impact on virtually every sector of modern life. Although we do not propose to elaborate such a policy in detail, we shall take the opportunity to comment on several kinds of societal responses that have emerged in recent years, to extract appropriate morals, and, at the conclusion, to indicate, however briefly, some elements such a policy might contain.

What Is Technology? A Dimensional Analysis

The nascent field of technology studies is littered with unsuccessful attempts to capture and display the supposed Platonic essence of technology in a succinct phrase or two. Examination of the literature reveals an extraordinary divergence in the numerous definitions proposed.[1] This divergence, not always apparent in scholarly or lay discourse about technology, is usually present and often vitiates discussion of important issues. Failure to specify clearly what one means by "technology" has resulted in persistent, mistaken, and misleading identification of technology with science, applied science, "hardware" (material artifacts), or with all the "products of technology" (material artifacts and procedural systems, which together will be called, for brevity, "technics" in what follows). Rather than advance yet another essentialist definitional candidate, we prefer the following characterizational approach. It is useful to distinguish between the *form* and the *content* of technology.

Regarding the form, in what follows "technology" will frequently be used to refer to a distinctive form of human cultural activity, like religion, sport, medicine, science, art, and philosophy. For any such form of human activity we may distinguish six general aspects or components:

1. Its output or products
2. Its function or functions
3. Its resources
   - A. Input resources (what is acted upon in the course of engaging in the activity-form)
   - B. Internal or transforming resources
     - i. that in accordance with which input resources are transformed
     - ii. that with which input resources are transformed
4. Features of the processes in which the form of activity is carried out
5. The mental sets of the activity's practitioners
6. The socio-cultural-environmental context of the activity

What is most distinctive about technology viewed as a form of human cultural activity is the nature of its output and its general function, purpose, or objective. The ultimate output of technology consists of material products and procedural systems for the production, management, and use of material artifacts, and for the control and enhancement of other forms of human activity, created with a view toward expanding the realm of practical human possibility.

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In these respects technology may be contrasted with science, whose most characteristic output is knowledge sought with a view toward achieving an enhanced understanding of some aspects of the natural world. Thus technology and science are distinguishable forms of human activity that at times in the course of their historical development have been virtually isolated from each other and at other times, closely intertwined. More generally, technology can be located on the map of forms of human cultural activity by comparing it with other such forms along each of the six above-mentioned axes. Moreover, as we shall see below for the modern period, technology in a given historical epoch (for example, medieval technology) can be usefully characterized by elaborating the specific nature of one or more of its six components in the epoch in question.

In brief, technology can be characterized as that form of cultural activity devoted to the production or transformation of material objects, or the creation of procedural systems, in order to expand the realm of practical human possibility. Its input consists of raw or already processed material and bodies of information; its characteristic internal or transforming resources are know-how (methods, procedures, techniques) and knowledge of the properties of its input resources; its characteristic nonintellectual resources include energy, information, tools, and perceptual and neuromuscular skills. Characteristic of the processes in which the activity-form technology is carried out is their fabricative, transformative nature and the presence of at least a rudimentary element of design. Whereas technology can be differentiated from other activity-forms by specifying the particular nature of the first four aspects, it is not obvious that there is anything distinctive about technology's socio-cultural-environmental milieu (#6) or the mental sets of its practitioners (#5) as opposed to those of other activity-forms. One might speculate, however, that technology differs from other activity-forms in that the natural environment—both in respect to the meteorological and creature-related threats it poses to human survival, and the spatiotemporal obstacles it presents to human desires for communication and transport—is a factor that more powerfully and more directly conditions technology than is the case with other cultural forms, for example, religion and art.

As for the content of technology, let us define *a technology* as the complex of knowledge, methods, and other resources used in making a particular kind of product or in creating a particular procedural system. For precision we must qualify this definition by adding "at a given time in a particular society." Thus the content of technology at a given time in a particular society (say, modern Western society) consists of the ensemble of all the technologies (rocket technology, telephone technology, and so on) used to produce all the technics in use at that time in that society.

Finally, we reluctantly acknowledge the loose and confusing use of "technology" by many people in ordinary speech as referring to the ensemble of kinds of products of technological activity, or to the ensemble of all products of technological activity (i.e., technics) in use in a society at a particular time. In fact, even more confusing is that many people use "technology" to refer to the ensemble of *modern* technics, thus inadvertently fostering, or succumbing to, the view that human history is divided into pretechnological and technological epochs. In fact, anthropologists hold that technology is a characteristic activity

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of *homo sapiens,* although, as the recent work of Goodall and associates shows, man is not the only toolmaking species.[2]

In short, discussion about technology would profit from recognition that "technology" can be used to mean or refer to a specific form of human cultural activity; to the content of technology, consisting of the ensemble of technologies used to make the various kinds of material products and procedural schemes in use in a society at a particular time; or to the sum total of the technics in use in a given society at a particular time.

Characteristics of Modern Technology

We shall now examine each of the six aspects of technology understood as a form of human activity, with the objective of elaborating noteworthy, specifically modern characteristics of modern—including contemporary—technology.

CHARACTERISTIC FEATURES OF THE PRODUCTS OF MODERN TECHNOLOGY

Complexity—A significant portion of the products of modern technology, especially in the twentieth century, are of unprecedented complexity. They are composed of hundreds, if not thousands, of parts, and may be viewed as complex technical systems, often hierarchically integrated. Yet, it is not the sheer *number* of parts that produces this unprecedented level of complexity—after all, some of the great Egyptian pyramids have over two million blocks—but that the parts in many modern technics are highly differentiated in nature and function and thus require extraordinary integration, a key determinant of complexity.

The Systems Context—Many products of modern technology, whether exhibiting interior systemic complexity or not, are intimately intertwined with, if not embedded in, complex sociotechnical support systems on which their manufacture, use, and maintenance depend, for example, telephones and cars. To purchase such items is to gain admission to a web of complex sociotechnical systems. To buy a car is, in a real sense, to buy into complex road, energy supply, parts distribution, maintenance, registration, insurance, police, and legal systems. The systemic "embeddedness" of modern technics has prompted critic Jack Burnham to make an interesting point in social ontology: "We are now in transition from an *object-oriented* to a *systems-oriented* culture."[3] To continue to view modern society as if it were simply a larger collection of admittedly more complex objects would be to overlook an essential dimension of the character of modern life—its systemic character. Conversely, to survey modern life through the conceptual lens of the system is to be better able to comprehend the nature, operation, strengths, and vulnerabilities of a growing number of human institutions and areas of human activity—the factory, the hospital, communications, and transportation. One might even speak of the progressive "systematization" of modern Western life. (Modern Western life as a whole may be better understood by regarding it as a complex web of interlocking, individually complex sociotechnical systems.) This development is also a double-edged sword: such systems are able to dispense diverse goods and services to large numbers of people unable to generate them by themselves (e.g., communica-

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tions, transportation, electrical energy, and a variety of manufactured products), yet this gain in human freedom must be viewed against the backdrop of the consequences of the occasional failure of such systems, either through incapacitating actions or breakdowns, that is, strikes or sabotage. Modern technological society is perched, seemingly precariously, on multileveled stilts, able to reach higher and see farther, but vulnerable to being tripped up and thrown off balance by recalcitrant forces.

One way the system-embeddedness of modern technics bears on formulating sound public policy for technology is the following. The assumption that replacing within a system one kind of technic with another deemed of greater quality will *ipso facto* result in improved overall system quality is unwarranted. For example, the Skolt Lapp people of Finland traditionally used reindeer sleds for their transportation. Reindeer were also a source of meat, and older Skolt males were repositories of knowledge and wisdom for the young on the care and use of reindeer. In the 1960s the snowmobile was introduced into Skolt Lapp society and rapidly displaced the reindeer sled. It substantially cut the time required to go to the trading post from the Skolt settlements, and offered access to better health care and more varied diets of foodstuffs and recreational activities. However, this improvement turned out to have a number of unforeseen negative effects. Older people, lacking the muscular dexterity required to run the machines, were displaced by the younger Skolts and rendered functionless. The reindeer herds were "de-domesticated" by the noise of the snowmobiles, and the number of calves declined significantly. Finally, the energy self-sufficiency of the old system—reindeer ate lichen off the tundra—gave way to dependence on imported petroleum and spare parts.[4] The moral here is clear: increases in "local" technical efficiency do not guarantee improved "global" system quality, a moral equally pertinent to the considerably more complex sociotechnical-environmental systems of contemporary technological society. An increase in "local" technical efficiency may cause a loss in systems stability, since technological change differentially affects the parts of the previously stable system of human relationships.

Relations of Modern Technics to Their Users—There is a spectrum of possible relations between a given item of technology and its users. At one end is the relationship to the designer/maker. At intermediate points are maintainer/repairer, optimizer, and tinkerer. At the other end is one who is only the user or operator. For example, in the case of the auto we can distinguish between the designing engineer; the Indianapolis mechanic who knows how to adjust a car to optimize its performance; the local garage mechanic who repairs and maintains cars; the lay person who can do a few simple repair or maintenance tasks; and the individual who knows only how to operate the car. With this spectrum of relations in mind, we can describe an important trend in the evolution of the relationship between modern technics and their users. Historically speaking, the long-term trend is away from the perennial situation, in which designer/maker, user, and maintainer were often one and the same person, toward a state of affairs in which a given individual stands in the relation of expert with respect to perhaps one category or subcategory of complex modern technics, and in the relation of mere user or operator to most others. This trend accounts in part for several interesting developments involving the products of modern technology.

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For example, modern technics are often regarded with mixed feelings of wonder, appreciation, awe, and anxiety: wonder and appreciation at their very existence and at what they make possible; awe at the precision with which they perform; and anxiety arising out of personal dependence on technics not understood and beyond one's control (for example, the computer and the jet airplane). The freedoms afforded by modern technics are often purchased at the cost of acquiescing in a sophisticated form of servitude.

Because of the machine-made, mass-produced character of most modern technics, the relations between them and their users are probably less intimate than formerly. To the extent that users can still be said to cherish some technics, this fondness is apt to be rooted not in the fact that these technics reflect the labor and talents of valued acquaintances and friends, but in their high quality and in the fact that, in possessing them, the possessor can claim superior status over nonpossessors. A seductive offer is made: present access to a great range of technics of astonishing capabilities, in return for accepting the possible future psychic consequences of surrounding oneself with depersonalized technics whose inner workings remain unintelligible to most users. This depersonalized relationship harmonizes well with the willingness to dispose of "old" items in favor of "new improved models," a disposition vital to the well-being of the advanced economies of the West as now structured. The sociologist Georg Simmel suggested that the proliferation of modern technics devoid of any personal relationship between producer and consumer/user results in a chaotic accumulation of these items in the life of the individual, such that these products do not undergo "fruitful inward assimilation"[5]—that is, they do not take on human meaning in subjective consciousness, much as knowledge can be absorbed and remain inert in memory as so many "knowledge stones"[6] (Nietzsche) without becoming harmoniously and usefully integrated into daily life. Writing in 1900, Simmel stated:

> The process of objectification of culture, based on specialization . . . is spreading to the sphere of personal daily life. Even in the early nineteenth century, domestic furniture, the useful or ornamental articles of the immediate environment, were, relatively speaking, extremely simple and durable, from the needs of the lower classes to those of the most cultivated. This produced that close personal bond between people and the objects of their environment which today appears even to the middle generation as old-fashioned eccentricity. . . . The mere number of specifically formed objects makes a close, as it were, personal relationship to individual objects difficult. A small number of simple objects can be more easily assimilated by the personality, whereas an abundance of various articles becomes, so to speak, an adversary. . . . we are, at bottom, indifferent to all those objects which crowd in on us, for reasons specific to a money economy: their impersonal origin and easy replaceability. . . . the objects of culture increasingly evolve into a world with its own coherence which touches the subjective soul, with its desires and emotions, at fewer and fewer points.[7]

Ubiquity—Another feature of the many products of modern technology is their emerging global ubiquity. (In this regard, the move toward modernization in China is a phenomenon of more abiding importance than recent attempts to reverse the modernization process, for example, in Iran, Cambodia, and earlier in China in the "cultural revolution.") This is a new and significant development

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in the history of technology and one that is growing: in speed, in the number of quasi-ubiquitous technics, and in the demise of remaining cultural, political, and economic barriers to complete ubiquity. This development was made possible by modern transportation and given great impetus by the transistor radio. Mass production systems, as well as international trade arrangements and incentives of profit and prestige, are among other factors fueling this trend. As usual, the results are mixed. On the positive side, the emerging global character of modern technology may hasten the final demise of the phoenix of xenophobia. On the problematic side, in instances where there is a sudden infusion of modern technology, as in some Arab countries, the fate of the integrity of indigenous cultures is in doubt. Some fear that the rapid global dissemination of modern technics is promoting the homogenization of world culture, with behavior patterns associated with the adoption and use of modern technics paving the way for leveling of differences in work, leisure, and consumption patterns, leading ultimately to a convergence of values and world views. Others contend that just as advanced technology has proved compatible with radically different political orders, so also patterns of thought and behavior bound up with the adoption and use of modern technics are compatible with a variety of different cultural systems. Granted, one does not expect to see the rapid disappearance of the various outward manifestations of cultural traditions, for example, dress, rituals, foods. However, in the wake of growing awareness in a modernizing society of the multiplicity of cultural traditions, of awareness that one's culture is merely one of many and not "made in heaven," it seems likely that inner allegiance to one's cultural heritage will become more and more perfunctory, display of its outer trappings more a habit than a spontaneous and natural emanation. The actual effect of the globalization of technics on the integrity of a host society's culture may turn on a further consideration: whether its government is autocratic or relatively democratic. Perhaps the Saudis will succeed in maintaining the integrity of their Islamic heritage by simultaneous rigorous enforcement of traditional behavioral norms. Evidence of the psychic impact of the globalization of technics (and their support systems) is still sketchy. However, the work of Inkeles and Smith[8] and a study in progress by Rosen et al.[9] on impact of industrialization on the mental health of industrializing and control groups of Shetland Islanders suggest that, under certain conditions (for example, allowing the people affected to participate in plans to minimize disruption of their way of life), modernization may in fact lessen the incidence of psychiatric disturbances in certain groups.[10] Thus, even if cultural leveling through rapid technology transfer were to take place, one cannot simply infer that this will exact a steep psychic toll.

One moral of these remarks is that, if natural environmental, cultural, and social disruption in the recipient country is to be minimized, consideration should be given by policymakers not just to maximizing the speed and volume of diffusion of modern technics into developing countries, but also to the manner in which the diffusion takes place.

Procedural Systems—Still another feature of modern technology is the emergence of procedural and organizational systems as technologies. Previously, technology had been concerned only with the production of material

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artifacts. Procedural systems provide specifiable and transferable schemes for the production, management, or use of material artifacts (for example, computer "software" in the form of languages, operating systems, and so on, and the methods of systems engineering and systems analysis). They also provide procedures for the control and enhancement of other forms of human activity (for example, management and organization theories and practices, teaching and training procedures, and so on). Whereas technologies for material artifacts generally arise from the natural sciences, these new technologies are often drawn from the social and behavioral sciences and from mathematics. The increase in complexity of institutions and institutional relationships and in technologies producing material artifacts, together with a sharp rise in the social and behavioral sciences, all have contributed to the development of this new and uniquely modern area of technology.

Important Effects on Modern Western Society—It is impossible to encapsulate the many more and less obvious effects of technology on modern society. An adequate account of technology's impact on modern life would have to address not only its pivotal role in generating unprecedented levels of material well-being and broad satisfaction of basic human needs, but also its role in transforming the natural and man-made environments; its bearing on the evolution of social organizations and institutions (the military, the corporation, the family, including the changing condition of women and children); its interrelationships with ideational phenomena such as value systems, world views, belief systems, core concepts (progress, the good life, human nature), and attitudes (toward cultural patrimony, land, social roles); its impact on psychic phenomena and well-being; and its role in altering the content, and reshaping the practice, of the professions and, more generally, the transformation of work (and leisure).

There are, however, several broad concepts that help one focus on important subclasses of these effects, and in so doing grasp important technology-engendered aspects of the character of modern Western life: scale, multiplicity, flow, and transience.

Scale and multiplicity. In the expression "the scale of life" in, for example, modern society, "scale" has at least three magnitudinal dimensions. The basic elements in human environments include people, technics, and social organizations. Magnitudinal dimensions of scale—number, size, and power—express the relative greatness of these environmental elements and others closely related to them, for example, choice. In general, modern life can be characterized in terms of its greatly increased numbers of people, technological products, and social organizations, increases made possible largely by modern technology, for example, medical and production technologies. The multiplicity of options open to most people in modern Western life is another salient characteristic, options regarding the acquisition of technological products, foods, leisure-time activities, places to visit, ideas, belief systems, world views, and so on. Appreciation of the increased multiplicity of modern life must be tempered by recognition of the fact that, as technology unfolds "the carpet of 'increased choice' " before us, the carpet is, to a degree, simultaneously rolling up behind us.[11] It would be disingenuous to suggest to a resident of Los Angeles County that, whereas our

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ancestors had only the horse, we have a greater choice in transportation modes: the horse or the car.

Regarding *size*, in some instances, access to products of modern technology, in the form of nutritionally balanced diets, has increased the life span and even the average physical size and capabilities of people. More characteristic, however, are the remarkable increases in the size of material artifacts and social organizations. In 1917 the largest coal-burning steam shovel had a capacity of a few cubic yards per bite. Today an electric-powered drag-line earth-mover, evocatively called "Big Muskie," is used in strip-mining. As tall as a 32-story building, its bucket scrapes the earth as it is hauled toward the machine at the end of a 310-foot boom. The bucket capacity of this $25 million technic is 220 cubic yards, and its 170 electric motors enable it to move 4 million cubic yards of earth per month. Equally staggering increases are evident in the size of the largest modern social organization, the private corporation, whether measured in terms of sales, number of employees, assets, number of stockholders, or profit. Some four hundred U.S. companies have sales of a billion dollars or more, and more than twenty exceed ten billion. The American Telephone and Telegraph Company and its subsidiaries, the world's largest corporation, currently employ nearly one million people and have over $100 billion in assets. The increased sizes of human settlements, gatherings of people for particular occasions, (say, the Normandy invasion of June 1944), and the extent of modern sociotechnical systems—global and emerging interplanetary transportation and communications systems, for example—are equally unprecedented creatures of modern technology.

Regarding the *power* of modern technics and social organizations, the destructive power of contemporary weaponry and the productive power of many modern manufacturing firms are orders of magnitude greater than in the nineteenth century. The question of whether modern technology has enhanced or diminished the power of the individual cannot be answered simply. A prudent answer is that the individual's power in various sectors has increased through technology—increased mobility, increased access to knowledge, increased control over human reproduction—at the cost of decreased self-sufficiency in these and other areas of human activity (work, leisure, food production). In general, modern technology has yielded greater multiplicity, the emergence of megaentities, increasing organizational and technical power, and, in the case of the individual, increasing power through technology coupled with decreasing power to effect meaningful changes in the organizations and sociotechnical systems that are the sources of that increasing power.

Alfred D. Chandler has documented the complex interrelations of these three magnitudinal dimensions of scale in tracing the rise of the modern business enterprise. New technology engendered efficient, large-scale sociotechnical systems of communication (telegraph and telephone) and transportation (railroad). This in turn made possible information about, and access to, large markets for the unprecedented output and responsive movement of goods generated by new mass-production technology. The powerful large-scale, multiunit modern business firm, with its "hierarchy of middle and top salaried managers to

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monitor and coordinate the work of the units under its control," was the key institutional response to "the rapid pace of technological innovation and increasing consumer demand during the second half of the nineteenth century."[12] In this sense, the large-scale modern business firm was as much an effect as a cause of modern technology.

Flow. The increased scale of modern life is intertwined with a greatly increased flow or "throughput"—material (people, products, energy, and material resources), ideational (ideas, values, knowledge, and information), and experiential—in various spheres of activity. To a significant degree, the health of most modern Western economies is critically dependent on increasing this flow throughout society's distribution channels, a flow both made possible and mandated by modern mass production, transportation, and communications technologies.

Transience. Closely related to, but distinguishable from, the flow characteristic is that of transience. There can be flows of homogeneous material or of material of changing composition. Transience arises from flows whose composition changes rapidly over time. The pivotal idea underlying the transient character of modern Western, especially American, life is the culturally reinforced notion that there are definite limits to the useful, legitimate, valid, or worthwhile lifetimes of phenomena, such that, once beyond those limits, the phenomena are "no good," useless, invalid, uninteresting, worthless. The transience of modern life is also made possible and mandated by modern flow technology and is manifested in such phenomena as being informationally *au courant*, annual models, disposable products, outmoded ideas, stale news, ephemeral cultural and artistic trends, and, generally, the cult of the new. Speaking of rapid changes of fashion—"and this by no means applies only to fashions in dress"—Simmel claims that they "interrupt the inner process of acquisition and assimilation between subject and object" that makes any kind of personal relationship between the individual and the fashionable product virtually impossible.[13]

Recent years have seen the emergence of a variety of embryonic countermovements that are rooted in the belief that the scale (including multiplicity), flow, and transience of modern life have reached excessive proportions, with negative consequences for human well-being. Regarding scale, one thinks of zero and negative population growth movements, of attempts to limit building sizes in San Francisco and the size of the community in Petaluma, California, the proliferation of antitrust cases against large corporations, and the proposal of legislation prohibiting mergers of corporations on the grounds of size alone. Regarding multiplicity, the Quaker Simple Living Project, for example, reflects growing concern over the increasing scale of modern Western life. Regarding flow, recently there have been advertisements for products addressing what the companies that produce them apparently feel is growing anxiety at the prospect of inundation by the ocean of information surging through society's communications channels. Personal computers and word processors, it is claimed, will make that sea negotiable, while various publications—digests—will make its essentials assimilable. Regarding transience, nostalgia crazes and the explosion of interest in "roots" suggest that many people sense they pay a psychic price by being suspended in a turbulent, flux-charged cultural environment. While mod-

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ern technology in part makes possible these general characteristics of modern Western life, modern man must also find these characteristics at least somewhat congenial. It would be a distortion to picture these aspects of modern life as imposing themselves on resisting, helpless individuals. For Nietzsche, it is the decline of a shared sense of life as absolutely meaningful, the sense of spiritual homelessness in posttraditional Western society, that provides the fertile soil in which these features of modern life take deep root, as would-be surrogate sources of meaning:

> And now the mythless man stands eternally hungry, surrounded by all past ages, and digs and grubs for roots. . . . Let us ask ourselves whether the feverish and uncanny excitement of this culture is anything but the greedy seizing and snatching at food of a hungry man. . . . On the heights we encounter the same overabundant lust for knowledge, the same unsatisfied delight in discovery, the same tremendous secularization, and beside it a homeless roving, a greedy crowding around foreign tables, a frivolous deification of the present, or a dully dazed retreat—everything *sub specie saeculi,* of the "present age." And these symptoms allow us to infer the same lack at the heart of this culture, the destruction of myth.[14]

Whether or not Nietzsche's analysis is valid, these countermovements suggest a growing awareness of problems that stem from increases in scale, multiplicity, flow, and transience, and the belief that changes likely to result in further increases in these properties should be subjected to critical empirical scrutiny, with a view to maintaining or enhancing the quality of human life in both its psychic and somatic aspects. This embryonic and perhaps ephemeral trend parallels the physical limits-to-growth debate, and might be described as a movement to question whether cultural limits to growth are in order. In our view, introduction and implementation of such cultural limits might, except insofar as mandated by shortfalls of material and energy resources, be more difficult to achieve than overcoming the allegedly ineluctable physical limits to growth.

THE FUNCTIONS OF MODERN TECHNOLOGY

As stated, the basic function of technology is the expansion of the realm of practical human possibility. Technology as a perennial form of human activity arose because, unaided by technics, human capacities are quite limited—for example, locomotive, perceptual, and mental abilities, and the abilities to lift, carry, dig, cut, see and hear, resist disease and the elements, perform arithmetical operations, and so on. Consequently, frustrated by his physical limitations and subject to harm from various creatures in, and aspects of, his environment, man attempts through technology to overcome his shortcomings and his vulnerability by extending his limited capacities. He thus enhances his power, which in turn often enables him to survive, and, on occasion, even to thrive. There are at least six ways through which technology extends the realm of practical human possibility: (1) extension of human faculties, directly through hearing aids, telescopes, microscopes, and megaphones, and indirectly through newspapers, television, and records; (2) increasing the efficiency of human activities through power saws, automobiles, electronic calculators, typewriters, and the like;

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(3) reducing or eliminating risk through contraceptives, seat belts, catchers' masks, and so on; (4) substitution, for example, of automatic dishwashers, lawn sprinklers, and phone message-recorders; (5) qualitative innovations in human activity—flying and predetermination of sex of offspring; and (6) expansion of means for expressing inner life—sculpture, painting, musical instruments, and biofeedback machines.

What of the functions served by technology in modern society? First, modern technology is embarked on a long, although brisk, march through the entire range of human faculties and capacities, the ongoing thrust of this effort being the extension (in some sense or other) of as many as seem useful or possible. These have progressed from initial simple extensions of muscular abilities, to locomotive and perceptual abilities, to augmentation of certain mental abilities (memory, logic, and calculative abilities through the computer), to the making of more and more comprehensive prostheses (for example, the artificial heart), and to the performance of biological functions and capacities (artificial insemination and *in vitro* fertilization). It is difficult to specify any human faculty or ability that is or would be viewed a priori as an ineligible target for technological extension. There will no doubt be ephemeral expressions of concern at the appearance of some new extensions such as the recent accomplishment of *in vitro* fertilization. However, when such extensions are used to assist individuals suffering from medical disabilities, as in the first *in vitro* case and in the use of prostheses, ethical, religious, or cultural objections seem heartless and caviling. One indication of whether any limits will be set on technological extension of human intellectual and perceptual functions, and functions susceptible to prosthetic substitution, will come when the proposed extension is not to compensate for a disability but, rather, to enhance significantly some nonimpaired faculty or ability for reasons of economic gain or mere convenience. Would, for example, ectogenesis be permitted without qualification if an artificial womb superior to its natural counterpart were developed?

This touches on one important reason that modern technology precipitates so many difficult issues of ethics and conflicts of human values. In each of the six modes listed above, extension can go, and in numerous cases in recent years has been thought by some groups to have already gone, "too far," thus raising an ethical or values issue. One thinks of the quantum leap in human ability to inflict destruction represented by nuclear weapons; of the enormous increase in tree-felling abilities in methods used for clear-cutting forests; of the incursion into wilderness areas of off-road vehicles; of the introduction of contraceptive technology in certain cultural milieus; and of conflicts over requiring helmets for motorcyclists and seatbelts or airbags for motorists.

Other functions have emanated from the basic one of extending the realm of practical human possibility. Although not unprecedented in human history, these functions have become quite characteristic of modern technology. Some yield benefits for producers; others for consumer/users.

For example, modern technology serves the function of enabling producers to make a financial profit and achieve corporate growth through production and sale of technics. This function is, of course, related to technology's basic function: people buy items of technology because these items typically extend the user's faculties or capacities. Or, technology can serve as a source of profit by

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effecting greater efficiency in the making of the product—for example, by development of less expensive substitute materials with all the requisite properties.

For consumers, modern technology has increasingly become an important source of personal identity and self-esteem. As religion, race, class, sex, and nationality become progressively less able to serve that function in achievement-oriented, posttraditional society, the items of technology an individual possesses and in which he or she is reflected have, along with work, become increasingly important sources of identity. For people who do not have prestigious positions or who do unsatisfying work, technology may well become the primary source. There is emerging a technology/identity relationship analogous to the physiological/psychological relationship encapsulated in the expression "*man ist was er ist*" (Feuerbach). As personal identity becomes fragile in modern society, producers utilize advertising to suggest that one can acquire an identity and garner self-esteem—and the esteem of others—by purchasing (and displaying) the right technics.

Another important function for which products of modern technology are used by consumers is that of passing or "killing" time. The modern "technologized" entertainment or "culture industry" (Elémire Zolla)—movies, records, and television—is so successful because of the abundance of relatively inexpensive, convenient ways it offers to pass time that otherwise lies heavy on hands and mind.[15]

CHARACTERISTICS OF MODERN RESOURCES

The resources component of technology as a form of human activity can be broken down into input resources (the matter that is to be acted upon and transformed in the course of the productive process) and transforming resources (the resources brought to bear on the input resources and through which they are transformed into the output or product).

Input Resources—The input resources of modern technology have several characteristic features. First, in earlier periods input resources typically consisted of basic raw materials as found in nature and obtained locally. In modern technology they are frequently already highly refined materials specifically developed to have certain desired physical properties (for example, steel or synthetic semiconductor crystals). As such, they are often the output of sophisticated scientific-technological activity, are composed of materials not found ready-made in nature (plastics and alloys), and are obtained from sources around the world.

An emerging pattern regarding input resources involves the dynamics among several conflicting developments: *globalization* (the growth of technological activities requiring resources obtained at present from sources located around the world); *fragility of resource access* (due, for instance, to internal political instability or the creation of cartellike organizations among groups of countries that largely control important input resources); *technological interdependence* (establishment of stable relationships involving exchange of technological products and know-how for needed input and energy resources); and *internalization* (the attempt by a country critically dependent on globally obtained input resources to attain relative independence by developing its own internal supplies or

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by technological substitution). A critical question regarding future interrelationships among these phenomena is: Will the combination of moves toward technological interdependence and internalization be sufficient to enable the developed countries to surmount problems of fragile access associated in recent years with globalization? That we live in the postcolonial era gives special impetus to such resource-related efforts.

Transforming Resources—Transforming resources are "first-order" resources, with which input resources are transformed, and "second-order" or "meta-transforming" resources, in accordance with which first-order resources are brought to bear on input resources. First-order resources include energy, tools, machinery, mechanical systems, labor power, capital, information, and other materials, such as chemicals. Changes characteristic of modern first-order resources include the increasing role of machinery over tools and labor power, the growth of automated production processes, the indispensable function of capital in making possible the development of modern large-scale productive processes, and changes in typical energy forms: coal, electric, and nuclear over animal, human muscle power, water, and wood.

Second-order resources are of two general kinds: methodic and epistemic. Technology is an essentially methodical form of human activity. Method in however rudimentary a form is present in making a technic in one way rather than another; in the selection, preparation, and testing of input resources and certain first-order resources; in the nonarbitrary ordering and integration of the various stages of the productive process to optimize the outcome; and in designing and testing the product, whether a model or at full scale. Traditionally, the most important technological method was the so-called cut-and-try, or trial-and-error, method. A modified trial-and-error procedure was used by Edison in searching for the best filament material for his incandescent electric light bulb. Modern technology employs an array of systematic methods—mathematical and physical modeling, dimensional analysis, similitude techniques, descriptive geometry, design techniques (for example, computer-aided integrated circuit design), control volume analysis, testing methods (wind tunnels), systems engineering, and "parameter variation."[16] The enormous increase in the speed and power of computation brought by the computer has greatly enhanced many of these methods.

Some of these methods came into prominence in modern technological practice because of certain characteristic aspects of modern technology discussed above. For example, consider systems engineering and parameter variation. The rise of the former method stems from the embeddedness of modern technics in complex large-scale sociotechnical systems. There is thus a need for obtaining and methodically interrelating knowledge of the properties of the system(s) in which the products are to be deployed and used; aspects of the design, development, testing, and manufacture of the product; and the needs and wants of product customers, operators, and users. Parameter variation owes part of its *raison d'être* to recurrent social, economic, and political exigencies (the limited financial resources available for a particular project, intercompany competition, or urgent national military need) that will not permit delay of a pressing project until basic scientific understanding of all facets of a problem has been attained. More generally, the impulse to elaborate systematic methods in modern tech-

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nology is fueled by the scale of the stakes involved in many of its projects (for example, the Apollo Project).[17]

By the epistemic resources of technology we mean the belief systems—justified true beliefs (knowledge) as well as erroneous beliefs—on which technological activity rests at a given time, or in accordance with which it is, for better and/or worse, carried out. There are at least three kinds of technological knowledge: knowledge of the materials and energy forms used in technological activity; knowledge of the methods used in various phases of the total product-making process; and design knowledge—of the kinds of design features appropriate to the criteria stipulated for the product, and of design data generated either in model-testing or in testing the performance of the technic itself. The case of the tubular, riveted wrought-iron Britannia Bridge constructed between 1846 and 1849 across the Menai Straits in Northwest Wales illustrates the generation, use, and diffusion of each of these three kinds of technological knowledge.[18]

To indicate what is characteristic of modern technological knowledge, we must distinguish between three bases of that knowledge: knowledge based solely on sense experience (knowledge of the properties of wood utilized by early North American Indians in making birch-bark canoes); knowledge derived from systematic application of experimental parameter variation to a phenomenon (in optimizing catapult, waterwheel, and airplane propeller design); and knowledge rooted in scientific understanding (the knowledge that went into the development of the transistor and lightwave communications cables). Knowledge in modern technology rests less and less on the first basis, more and more (but not exclusively) on the third basis. However, as already mentioned, even in modern technology, empirical methods must be employed to compensate for a recognized lack of scientific knowledge and understanding. In the Britannia Bridge case, since its completion was the key to opening the London-to-Dublin rail connection, and since its construction would take at least three or four years, "the engineers had to proceed on the basis of incomplete knowledge, a common occurrence in novel and expensive projects."[19]

Another characteristic of modern technological knowledge, especially that body based on scientific understanding, is that it is itself obtained with the aid of sophisticated products of modern technology—electron microscopes, computers, spectrographs, and so on. "Modern science as applied technology" is no less true and no more misleading than "modern technology as applied science."

A third characteristic of the knowledge base of modern technology is that this knowledge is *not* always generated with a particular immediate technological need in mind. The motivation for pursuing it is often much more generalized, perhaps consisting of a belief that a particular field of inquiry may in the intermediate or long run prove technologically fruitful. The transistor was invented some years after the Bell Laboratories undertook basic research programs in solid state physics, in the belief that it would turn out to be a fruitful field of inquiry, but in the absence of specific plans or evidence for applicability. There is thus a kind of stockpiling of such knowledge for possible future technological application. Contributions to the knowledge base of modern technology come from around the world and are disseminated through various established formal and informal diffusion mechanisms, such that a new

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contribution may rapidly find applications at some remove from its initial projected technological use. These facts sound the death knell for the traditional heroic theory of invention in regard to modern technology.

CHARACTERISTIC FEATURES OF MODERN TECHNOLOGICAL PROCESSES

Recently there has been a spate of incidents involving technological failures of one sort or another, where the parties responsible for the design of the technology have been at odds with either the manufacturers, operators, and/or those charged with product maintenance, over who should be held responsible for the breakdowns. The Three Mile Island episode, the O'Hare DC-10 crash, the collapse of the Kemper and Hartford arenas, and the recurrent malfunctioning of subway systems in New York and San Francisco are cases in point. This development occurs at a time when, in the name of protecting the public interest, efforts are underway in the federal government to disaggregate certain private large-scale technological enterprises that provide important national services or products, enterprises that possess integrated planning, research, development, manufacturing, and operations arms. These technological breakdowns seem to be due in part to a lack of coordination or communication between parties responsible for the different phases of the product life cycle. The degree to which disputants' positions are determined by a priori ideological prejudices, vested economic or bureaucratic interests, and empirical evidence of the consequences for the public interest of choosing one rather than another of the possible modes of relationship between the units responsible for phases of the product life cycle (dispersed responsibility versus vertical integration), merits close scrutiny in the formulation of sound public policy on technology.

Another identifying characteristic of the processes of modern technology is their predominant locus, the modern research and development laboratory and, where applicable, the organizational parent that supports it. As invention and innovation have become less the achievement of the heroic individual and more the accomplishment of an integrated team of specialists, the locus has moved from the individual workshop to the organization's headquarters, laboratory, and plant. Bell Laboratories, to take an example familiar to the authors, is a laboratory of such size, organizational complexity, and human, technical, and financial resources (about 20,000 employees, of whom 2,500 hold PhDs, eighteen locations, and an annual budget of over $1 billion), that it is not even recognizably similar to the prototypes of Edison in Menlo Park and of Siemens, Krupp, and Zeiss at the turn of the century in Germany, to say nothing of the Wright Brothers' bicycle shop. Even the successful entrepreneur soon sees his organization grow rapidly, from a very few technical innovators to a large organization with many of the complexities of established companies (Hewlett-Packard, Intel, and Digital Equipment Corporation).

CHARACTERISTIC MENTAL SETS OF PRACTITIONERS OF MODERN TECHNOLOGY

Because of what Derek de Solla Price has called the "papyrophobic" nature of engineers vis-à-vis their work,[20] it is difficult to ascertain if or how the con-

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sciousness of the practitioners of modern technology differs from that of their premodern predecessors. Whether premodern engineers were more or less efficiency- or cost-conscious or more or less mindful of aesthetic and environmental considerations in their work is difficult to determine. In the last decade, however, a development has taken place that seems unprecedented in the recorded history of the engineering profession. Most practitioners of modern technology are employed in the private sector. This has typically meant that engineers who wished to keep their positions could ill afford to give public expression to qualms about ethical, social, political, or environmental aspects of their work. In a 1972 survey of 800 randomly selected members of the National Society of Professional Engineers, a good many were sufficiently fearful of employer retaliation that they would "swallow the whistle" rather than become "whistle-blowers" if they found themselves confronting activities of their organizations that they considered contrary to the public interest. Almost half of the respondents indicated they felt "restrained from criticizing their employer's activities or products," and over 10 percent felt that they were "required to do things which violated their sense of right and wrong."[21] However, in recent years there have been a growing number of cases in which engineers have "gone public." Several possible factors underlie this development, including awareness of the behavior of scientists and engineers in Germany in the 1930s and 1940s; familiarity with the horrific effects of the use of some products of scientific and technological research and development during the Vietnam War; recognition of the nature, magnitude, and scope of the negative impacts likely to result from the malfunctioning or misuse of certain modern technologies; and widespread knowledge of several recent celebrated cases of whistle-blowing engineers.

These developments have been reflected in renewed interest in codes of engineering ethics within professional engineering societies. In 1978 the Member Conduct Committee (MCC) of the Institute of Electrical and Electronics Engineers (IEEE) conducted its first formal inquiry into the dismissal by her employer of a computer programmer, an IEEE member who had gone public after receiving from her superior what she regarded as an unsatisfactory response to her concerns about the efficacy of a computerized police emergency dispatch system. The member was judged by the MCC to have adhered to the letter and spirit of the IEEE Code of Ethics, and cleared of any charges of professional irresponsibility.[22] In September 1978 the IEEE Committee on Social Implications of Technology honored the three former BART (Bay Area Rapid Transit) engineers with its first "Award for Outstanding Service in the Public Interest," awarding each a check in the amount of $750. The engineers had called attention to what they regarded as unsafe and unreliable aspects of BART's Automatic Train Control System, later confirmed by a BART crash.[23] In parallel with such developments, academic interest in engineering ethics is currently growing, much as did interest in bioethics in the early 1970s.

One important issue on the legal agenda in coming years is likely to be the question of the rights of whistle-blowing engineers vis-à-vis their employers. In this connection, the Committee on Scientific Freedom and Responsibility of the American Association for the Advancement of Science has identified eight public laws that include "employee protection" sections. These sections "prohibit adverse actions by employers against employees who assist in carrying out the

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regulatory purpose of the legislation, for instance, by notifying responsible officials of legal violations or possible hazards regulated by the laws."[24] While such protection could open the door to abuse, responsible whistle-blowing could become a valuable adjunct to technology assessment. In sum, the mental sets of increasing numbers of practitioners of modern technology are likely to go beyond interest in "sweet intellectual problems," acquiescence in "quick and dirty" pragmatic solutions, and preoccupation with "getting on with the work," to encompass concern for professional responsibility in relation to the broader social and environmental aspects of their work.[25]

EXTERNAL CONTEXTS OF MODERN TECHNOLOGY

We have already touched briefly on some of the general effects of technology on modern Western life. We now turn to the other side of the coin: the impact of modern society on technology. Like other forms of human activity, technology is conditioned in various ways by the complex socio-cultural-environmental matrix in which it unfolds. This is important for two reasons. First, from the point of view of practitioners of modern technology and those who employ them, excellence in the generation and use of technological knowledge, methods, resources, and products is necessary but far from sufficient for the practice of a modern high-technology firm to be successful. To a degree unprecedented in Western history, practitioners of technology in contemporary society must also be adept at grasping the import of developments in various parts of the external contextual matrix and responding appropriately. Second, from the point of view of societal control over technology on behalf of the public interest, each matrix element can be considered as a lever for exercising that influence. The interrelations among the various matrix elements and subelements are myriad and complex. We shall limit ourselves here to identification of, and brief comment upon, six mechanisms of societal influence on modern technology: governmental, environmental, market, financial, social, and political.

The Governmental Context—The governmental context is set by the actions of four branches: executive, legislative, regulatory, and judicial.[26] The president can formulate technology-intensive policy proposals and submit them to Congress, and can influence the direction and speed of technological development by the priorities established in the federal budget as well as by the fiscal constraints embodied therein, for example, constraints on the money available for research and development through federal agencies and departments. The president can also appoint special committees to investigate problematic aspects of technologies and decide whether to develop, manufacture, and deploy government-supported defense-related technologies. An executive branch department can exert an important influence over technology by the priorities it establishes for allocating its research support; by specifying conditions that must be satisfied in conducting certain categories of research supported by department funds; by decisions permitting, denying, limiting, or mandating the use of technologies within a department's purview; and, in the case of the Justice Department, by deciding (perhaps in consultation with the chief executive) whether to investigate or prosecute alleged technology-related abuses or illegalities.

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The legislative branch exerts its influence over technology in various ways. It can approve or deny funding for various technology projects; pass broad pieces of legislation giving mandates to appropriate regulatory agencies in an attempt to realize certain objectives; and, as part of its legislative responsibility, commission its Office of Technology Assessment to carry out assessments of technologies involved in items on its current or probable future legislative docket. For example, Congress denied funding for continued development of an American SST, is considering revision of the Communications Act that would serve as the new mandate for the Federal Communications Commission, and has commissioned technology assessments of electronic funds transfer, appropriate technology, solar power satellites, and a proposed national computerized crime information system.

Although "Congress passed the first regulatory legislation and created the first agency empowered to supervise and direct the internal affairs of a sector of private enterprise in detail" in the mid-nineteenth century, in response to repeated boiler explosions in steamboats,[27] the regulatory branch is largely a twentieth century development. It conditions technology by the requirements its agencies set or the guidelines they issue governing the testing, marketing, operation, and use of various technologies. Its primary concerns are safety in the operation and use of technologies, and ensuring that their use or operation conforms to the standards set and objectives specified in congressional mandates addressed to the various agencies. Recent episodes involving the grounding of the DC-10 and the breakdown of the Three Mile Island nuclear plant raise serious questions about the adequacy of regulatory agency safety standards that must be satisfied before a technology is certified for use or resumption of use. To illustrate the other chief function of the agencies—implementation of congressional mandates—the National Environmental Protection Act and the Clean Air Act of 1977 gave the Environmental Protection Agency a mandate on the basis of which it has formulated regulations mandating, *inter alia*, annual inspection of auto exhaust in California, reduced traffic in certain parts of midtown Manhattan, and progressive reductions in the maximum permitted levels of noise from buses in San Francisco.

The judicial branch exercises a power influence on modern technological practice. It can uphold or overturn regulatory agency guidelines designed to implement congressional mandates bearing on the use of technology; it can review challenges to executive department decisions by special interest groups; and it can adjudicate patent law disputes involving new technologies, intercompany and Justice Department-initiated antitrust actions, and suits brought by private parties against enterprises of individuals in hope of obtaining findings of technological liability in contract, tort, or property. According to David L. Bazelon, then Chief Judge, U.S. Court of Appeals for the District of Columbia Circuit, "Some two-thirds of the D.C. Circuit's caseload now involves review of action by federal administrative agencies; and more and more of such cases relate to matters on the frontiers of technology."[28] This touches on a serious problem for the judicial branch: adjudicating disputes involving technology where few judges have the knowledge to assess the merits of competing scientific arguments. In Judge Bazelon's view, "In cases of great technological complexity, the best way for courts to guard against unreasonable or erroneous

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administrative decisions is not for the judges themselves to scrutinize the technical merits of each decision. Rather, it is to establish a decision-making process that assures a reasoned decision [by the administrator] that can be held up to the scrutiny of the scientific community and the public."[29] It can be argued that this is not a satisfactory solution to the problem and that the courts can only meet their responsibilities by equipping themselves with at least some capability for understanding the evidence and reasoning that led to a decision. Finally, it would be well to mention one of the more controversial examples of technological litigation now working its way through the courts: a suit brought by attorneys from California Rural Legal Assistance on behalf of the California Agrarian Action Project and a group of farmworkers against the University of California Regents charging that they have allowed agribusiness corporations, and their own economic interests, to influence their decisions to spend public tax funds to develop agricultural machines. The relief sought by the plaintiffs includes an order to compel the University to use the funds the University receives from its farm machinery patents to help farmworkers displaced by those machines. Should the plaintiffs win their suit, the impact on American technological practice could be far-reaching.

The Environmental Context—The natural environment has, of course, always conditioned technology. For example, the nature of an environment (polar, desert, jungle) engenders the development of technologies appropriate to that environment to enable man to adapt successfully to it. Further, emerging scarcity of some technological resource may ignite a search for, and gradual transition to, a new technology using resources present in the environment in greater abundance, as, for example, in the case of the gradual change from wood-based to coal-based technology in England that began in Elizabethan times and stretched until the end of the eighteenth century.

In modern Western society, environment has begun to condition technology in new ways, although admittedly more indirectly. The safety and quality of the environment and public perceptions of it have begun to translate into presidential policies and congressional mandates to regulatory agencies to protect or enhance environmental quality or safety, occasionally even at the cost of some perturbation of the technoeconomic *status-quo*. In France, Italy, and recently the United States, political parties have been formed, organized largely around a complex of technology/environment issues. In general, in the last fifteen years, the gradual development of broad-based environmental awareness, the lobbying and litigious activities of environmental interest groups, and guidelines issued and enforced by the EPA in response to congressional mandates have markedly increased the heed paid the environment by many corporations in going about their technological activities. Both research and development priorities and capital investment programs of the corporations have been affected by this.

The Market Context—If voters affect technology through their elected officials and their appointees as well as through increased environmental awareness, consumers vote on technology with their purchases. The conditioning of technology by the behavior of a mass market is a phenomenon of the last century and a quarter, with the advent of mass production, distribution, and communications systems. Among the actors in this new drama are the practitioners

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of a new field of inquiry: market research. To thrive, the modern technology firm, faced with considerable time-lags for redesign, retooling, and retesting of a new product line, must be able to divine accurately the volatile parameters affecting the market: performance, economy, prestige, reliability, type of product desired, and so on. The rewards to those who closely monitor trends in the relative importance of these variables, and who quickly discern the underlying factors affecting these trends, are often substantial, as in the case of Sony television, Honda and Rabbit automobiles, Seiko watches, and Cuisinart food processors. The power of the market mechanism to affect technological activity is attested to by governmental intervention to alter the market by introducing various incentives or disincentives vis-à-vis certain technologies—tax credits for solar heating units, surcharges on "gas guzzlers," and import quotas on Japanese TV sets. Variously shaped by consumer needs and preferences and government interests, the market mechanism affects the speed, directions, and mutations of modern technological activity sometimes more than new developments within the field of technology itself. The combination of legal, legislative, and regulative activities, and the sensitive nature of consumer demand for technology gives modern society a *potentially* powerful arsenal of mechanisms with which to exert leverage to enhance technology's effect on modern society.

The Financial Context—Many large-scale modern technological projects require long-term, extensive research and development efforts before they come to fruition—the Apollo Project and the development of an electronically switched nationwide telephone network are good examples. This in turn requires adequate capital for the duration of the undertaking. Concern over the enormous power of modern corporations and efforts to break them up into smaller units of more modest power may conflict with the large-scale systemic nature of many important projects of national interest in contemporary society; the desire, if not the necessity, for their being carried out at the highest level of quality; and the fact that the requisite capital for the extended research and development phases of the project may be within the means of only the largest corporations. Companies subject to excessive governmental regulation may be hard-pressed to maintain stockholder dividends and generate the required funds if their profits are severely limited by regulatory agencies whose primary allegiance is to the minimization of short-term costs to individual consumers. Failure to appreciate the scale of resources necessary for such projects and the importance of assurance that they will be available for the extended duration of the project can undermine the will to undertake large-scale projects vital to providing for future social needs.

The Social Context—Two additional social mechanisms deserve mention. In recent years a new mechanism for the social control of technology has come into focus: the private citizen-initiated national, state, or local referendum. Such referenda have been held on a national level in Switzerland and Austria, and on the state level in California and a number of other states on nuclear power. In November 1979 the City and County of San Francisco held its third referendum of the 1970s on limiting high-rise office building construction. Although this process of democratic participation in public policy decision-making has to date been applied to only a few technologies, it may find increasing influence in

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the future as a vehicle for exercising direct social control of technology, subject, of course, to judicial review on constitutional grounds.

A second, more subtle way society influences modern technology is through its prevailing cultural climate. The reigning cult of the new in modern Western society strongly conditions modern technological activity and is in turn reinforced by technology's advertising support system. Similarly, deep-seated cultural values and attitudes toward progress, land, "the Don Juan ethic of experience" (more is better), child-bearing, death, freedom, comfort, and convenience foster the development (and legitimate the use) of technologies intended and thought to serve those values—for example, space-shuttles (progress), strip-mining technics (land), video cassette recorders ("the Don Juan ethic of experience"), artificial insemination (child-bearing), life-prolonging technologies (death), dune buggies (freedom), air conditioning (comfort), and TV dinners (convenience).

The Political Context—The political context can be divided into two subcontexts, domestic and international. The primary way domestic politics conditions modern technology is through electoral approval or disapproval of technology policies, and votes on technology issues of elected executive and legislative officials. Nuclear power is a current case in point.

That considerations of international politics exert a powerful influence on technological development that affects the development, testing, deployment, use, and transfer of certain technologies is scarcely new or news. These conditioning effects are, however, as important as they are perennial. Consider the ways American technology is currently influenced by the international political context. The SALT II treaty precipitated a presidential decision to proceed with the development of the MX missile system. On the other hand, the neutron bomb's development and deployment was deferred by, *inter alia*, the reluctance of certain allies to install the weapon in their own countries. The dependence of high technology markets on international politics is shown by the changing relations between American and China, and America and Iran. International politics also conditions technology transfer policy. Appealing to considerations of national security, President Carter in 1978 vetoed the sale of a powerful American computer to Tass, ostensibly intended for use during the 1980 Olympics. A different kind of limit on technology transfer is involved in the American response to demands by developing countries for rapid and liberal transfer of American technology: U.S. firms claim that technology is a form of proprietary knowledge, and labor unions say that export of technological know-how to developing countries means a loss of jobs for American workers. President Carter's proposal for an Institute for Technological Cooperation to educate more Third World scientists and foster international research in problems that affect the developing countries reflects a difficult executive dilemma: how to balance the long-term desirability of favorably impressing an increasingly influential body of international opinion against recognition of domestic economic realities and their short-term electoral consequences. In any event, the role of American high technology as a valuable bargaining chip in international political and economic competition is likely to grow in importance in the future.

It should be noted that these six conditioning contexts are often strongly interactive in relation to technological activity. Several may be simultaneously

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exerting supportive and opposing influences on a technological option or practice. Consider nuclear energy. The chief executive has called it indispensable; Congress is divided; the regulatory situation is in flux. Litigation opposing nuclear power persists; environmental considerations work both for and against nuclear power (if no nuclear power, then more air pollution from coal versus the problems of safe operation and storage of nuclear waste); and citizen referenda, although unsuccessful to date, have not been held since Three Mile Island. Market and financial conditions are uncertain, in part because of complex regulatory and judicial hurdles. Cultural considerations cut both ways (allegiance to continued growth versus increased concern over future generations). Finally, international political factors weigh both for and against (determination to achieve energy self-sufficiency versus concern that proceeding with nuclear power will place the United States in the position of antagonizing present or potential allies if it declines to transfer, or places stringent conditions on the transfer of, nuclear technology or its resources out of its fear of nuclear proliferation and concern that the technology will find its way to unreliable third parties).

This underscores our point that a modern high-technology firm must be adept in its initiatives and responses with respect to each of these six external conditioning contexts if it is to be successful. Such concerns give rise to a characteristic organizational feature of many modern technology firms: the existence of corporate units created specifically to attend to matters related to each of these six contexts.

Toward an Improved Public Policy for the Social Management of Technology

In the course of characterizing modern technology we have had occasion to note a variety of problems spawned by both the nature and use of its products. There is no definitive solution to the complex of problems noted. We shall conclude by offering several broad suggestions that we hope will ameliorate certain aspects of the situation.

EDUCATION One key to a more efficacious social management of technology lies in increased study in the field known as science, technology, and society (STS). In less than a decade this field has grown to a point where there are now some two hundred programs of varying size and focus in American colleges and universities. Recently, similar programs have begun to appear in England, Holland, and Scandinavia. STS has at least five subfields: ethical and human value aspects of science and technology; technology and public policy; the histories of science and technology and their interrelations; technology assessment; and the interrelations of technology, ideas, and social institutions in the history of culture. Study in this field on both undergraduate and graduate levels provides a new mode of liberal education appropriate to the nature and problems of the (modern) technological era. Whether viewed as complementary to specialized study in a standard discipline or as preprofessional training for future lawyers, business people, civil servants, and politicians, such education makes students sensitive to the benefits, costs, and risks, as well as the achievements, problems, potentials, and significance of modern technology. Judges and other decision-makers would benefit from a grasp of the rudiments of technology and from

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study illuminating the myriad obvious and subtle ways technology impinges on human welfare. Future and practicing engineers would benefit from education designed to induce them to attend to ethical and social aspects of engineering practice as a matter of course. Ordinary citizens would benefit from STS study by becoming better able to make informed decisions in their capacity as voters on technology-related issues. Such education might also be introduced by progressive technology firms, those that recognize the long-range benefits such "in-house" study would yield for its management. If there is to be realistic hope of meaningful democratic participation in the increasing number of debates over technology policy, from the international to the local level, such education bids fair to become essential for a broad range of citizens.

TECHNOLOGY ASSESSMENT Prospectively, technology assessment in public decision-making must be made more accurate and more comprehensive and taken more seriously. In assessing controversial technologies, attention should be paid not only to economic, environmental, and medical costs, benefits, and risks, but also to possibly intangible social, cultural, and psychic costs, benefits, and risks, insofar as they can be reasonably projected.[30] Technology assessment must be inherently structured, organizationally positioned, and temporally conducted so that it utilizes *good* information about the concerns, values, and needs of the public, and so that it can actually lead to a change in the projected technology or its use if the evidence adduced so warrants. This is no easy task, as the events surrounding the Kemeny Committee's review of nuclear power in the wake of Three Mile Island show. Midway through its inquiry, some panel members felt compelled to rebuke the Nuclear Regulatory Commission for what they regarded as its premature return to a business-as-usual attitude vis-à-vis the licensing of additional nuclear plants. On the other hand, if approval or rejection of a new or relatively new technology is to be a genuinely open question, provision may have to be made for enabling a company whose technology is rejected or severely limited to recover at least part of its investment through, say, tax credits. Otherwise, the willingness to invest corporate resources in new technology would be undermined.

LEGAL LIABILITY Prospectively and retrospectively, the concept of legal liability should be further refined to protect in advance against, or at least provide *post facto* relief for, a broader spectrum of negative technological effects. Whereas "in the infancy of the industrial era [there was] effective immunity from legal liability" for industrial enterprises, for "the past half-century or more, . . . as the emphasis upon quantitative economic development has begun to give way to a new stress upon qualitative improvement in various aspects of national life," "there has been a pervasive (if occasionally faltering) trend toward the imposition of civil liability upon economic enterprises for the reasonably foreseeable adverse consequences of their technological choices." In recent years, American courts of law have begun to support "a broader concept, that of liability for all injurious consequences [of producers' goods and devices], foreseeable or not." This new trend derives not just from the magnitude and extent of many such consequences, but from the fact that such harm as results from modern technologies is often caused indirectly (for example, toxic discharges from industrial operations into water supplies), manifest only in the long-term (such as radiation effects from atomic weapons tests and nuclear materials manufacturing

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plants on people far from the sites of these activities), and/or intangible in nature (loss of direct sunlight by people living near high-rise buildings). The historic process of making enterprises and individuals internalize the costs of their technological activities, costs traditionally regarded as externalities, is likely to continue, particularly insofar as long-term, empirical studies succeed in establishing subtle causal links between technological activities and personal injury. Such ongoing expansion of legal liability for technological activity not only provides opportunities for *post facto* relief for aggrieved plaintiffs, but can also contribute to the gradual emergence of "new professional attitudes and new entrepreneurial assumptions with respect to the obligations that accompany the use of science and the development and application of technology." Such changes can in turn lead to revision of private decision-making to reflect "deeper and more dominant concern"[31] for the indirect, remote, and intangible human and ecological effects of modern technological practice.

REGULATION While refining social control mechanisms to prevent, mitigate, or eliminate untoward effects of modern technological activity, it is equally important that parallel policy be developed to provide strong, positive incentives that foster technological innovations likely to contribute to the fulfillment of basic human and vital social needs. Such a policy should include case-by-case analysis of technology-related bodies of regulatory requirements, with the purpose of ascertaining if their respective costs—including direct administrative and compliance costs, and the indirect costs to the public incurred by foregoing the economic and social benefits—are justified in terms of the magnitude and distribution of social benefits they reap for human welfare. If the benefit/risk ratio of a new technology is favorable, its postponement—and thus greatly increased cost to society—or outright rejection may yield disbenefits that greatly outweigh the benefits of eliminating minor hazards.

There are other ways in which the regulation or limitation of technology may have important indirect or unforeseen side effects. Stopping one technology may result in the use of a more dangerous alternative. Conflicts between societal purposes may, through regulatory overemphasis on one purpose, result in costs or penalties to another purpose that are more serious to society than the matters being regulated. An example of this is the accumulation of regulations that led to a heavy dependence on imported oil, which set the stage for OPEC price rises beginning in 1974.

It is worth reflecting on Max Weber's paradox of modern social "rationality." As described by Giddens:

> The growth of the bureaucratic state proceeds in close connection with the advance of political democratization, because the demands made by democrats for political representation and for equality before the law necessitate complex administrative and juridical provisions to prevent the exercise of privilege. The fact that democracy and bureaucratisation are so closely related creates one of the most profound sources of tension in the modern capitalist order. For while the extension of democratic rights in the contemporary state cannot be achieved without the formulation of new bureaucratic regulations, there is a basic opposition between democracy and bureaucracy. This is, for Weber, one of the most poignant examples of the contradictions which can exist between the formal and the substantive rationality of social action: the growth of the abstract legal procedures which help to eliminate privilege themselves reintroduce a new form of entrenched monopoly which is in some respects more "arbitrary" and autonomous than that

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> previously extant. Bureaucratic organization is promoted by the democratic requisite of impersonal selection for positions, for all strata of the population, according to the possession of educational qualifications. But this in itself creates strata of officials who, because of the separation of their position from the external influence of privileged individuals or groups, possess a more inclusive range of administrative power than before.[32]

Mutatis mutandis, it is worth inquiring in particular cases whether the paradox here described applies to the relationship of regulated technological activity to shared values like the public interest, health, safety, and equal opportunity.

CULTURAL CRISIS AND RENEWAL The problems of modern technology cannot all be traced to imperfections in existing education, methods of technology assessment, liability law, and government regulatory practice. Some are products not of technology but of a growing cultural crisis in American life that manifests itself in various ways in technological activity. We shall focus on two examples. First, there is growing concern in knowledgeable circles that products of some important sectors of American technoeconomic activity are of mediocre quality—automobiles, television sets, high fidelity sets, furniture, and building construction. Thre is growing evidence of a decline in American craftsmanship, whether in product design, manufacture, or maintenance. The phenomena of prematurely obsolescent, disposable, high-maintenance products, of factory recalls, and incompetent repair work, together with the astonishing success of Japanese and West German firms in capturing significant, increasing portions of important product markets in America suggest, among other things, a decline of cultural values that once made such phenomena rare. This situation does not appear to be reversible simply by instituting more rigorous quality control mechanisms in the workplace—which is not to devalue their importance. The cultural crisis we refer to has many sources, including the legitimation of deception in product advertising; corner-cutting on product quality to maximize short-term profit; and the deep-seated feelings of many workers about their jobs—that they lack inherent meaning and hold little or no possibility for creative self-expression—and the feeling that they are not treated like people but regarded as replaceable parts subject to dismissal in the name of increased local efficiency. Such phenomena frequently translate into attempts to "get away with" doing the bare minimum necessary to complete assigned tasks, with little regard for considerations of high quality.

A second technology-related aspect of the American cultural crisis is related to the decline of civility in urban America. There appears to be a growing trend toward the use of a number of modern technics in ways that can only be called inconsiderate of the interests and welfare of others affected by such use. Consider the ways automobiles, motorcycles, snowmobiles, large portable radios and cassette tape machines, and high fidelity systems are used in public places and spaces. In the context of a general breakdown in traditional patterns of socialization in American society, and given the mass production of items of technology lending themselves to antisocial uses, the market mechanism and routine procedures like driving tests serve as sole gatekeepers governing individual access to such technics. Unfortunately, neither access to sufficient purchase funds nor possession of sufficient test-related knowledge to pass such procedural hurdles

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offer assurance of subsequent responsible and considerate use of technics. The problems connected with modern technology should not all be laid at the doorsteps of producers or government. A growing group of unsocialized—or socialized?—abusers of abusable modern technics are responsible for part of the criticism leveled (unfairly) at modern technology *per se*. Given the general demise of shared internalized cultural values and behavioral norms that could dispose users of technics to respect the interests of others, modern Western society, especially America, is relying increasingly on generating a more elaborate but often unenforceable set of external behavioral proscriptions, for example, the law of nuisance.

Short of a major cultural renewal in American society, a renewal that seems unlikely to occur, the problem of rekindling commitments to excellence in craftsmanship and to civility in the use of increasingly potent and portable technological products is likely to remain intractable. These two cultural phenomena contribute to what President Carter in his July 1979 energy address called the "crisis of confidence" of the American spirit, a crisis "whose symptoms . . . are all around us." The fact that it is easier to point to cultural facets of technology problems in contemporary society and suggest some of their causes than to specify steps for their solution should not deter one from recognizing the problems in their true dimensions.

The complex nature of modern technology and the diverse problems associated with its practice and products require the formulation of an improved public policy for the social management of technology. This effort must be commensurate with the dawning recognition that, in the words of Lawrence Tribe, "no task confronting civilization is more urgent than channeling technology to enhance rather than destroy the fabric of life and the dignity of man."[33]

References

The authors are indebted to Professor Harvey Brooks for his helpful comments and criticisms of an earlier draft of this essay.

[1]See R. E. McGinn, "What Is Technology?" *Research in Philosophy and Technology*, 1 (1978): 180.

[2]Not only do chimpanzees use tools—compressing chewed leaves, inserting them in water-filled tree trunks as sponges—but they engage in rudimentary toolmaking, stripping leaves off branches and inserting them into tree trunks to extract termites. See Jane van Lawick-Goodall, *In the Shadow of Man* (Boston: Houghton Mifflin, 1971), pp. 34-37, 98-99.

[3]J. Burnham, "System Esthetics," in *Great Western Salt Works* (New York: Braziller, 1974), p. 16.

[4]P. J. Pelto, *The Snowmobile Revolution: Technology and Social Change in the Arctic* (Menlo Park, California: Cummings, 1973).

[5]"The Future of Our Culture," in P. A. Lawrence, *Georg Simmel: Sociologist and European* (Sunbury-on-Thames: Nelson, 1976), p. 251.

[6]*The Use and Abuse of History*, T. Commons (transl.) (Indianapolis: Bobbs-Merrill, 1957), p. 23.

[7]"The Philosophy of Money," chap. 6, part 2, in Lawrence, *Georg Simmel*, pp. 209-210.

[8]A. Inkeles and D. Smith, *Becoming Modern* (Cambridge, Mass.: Harvard University Press, 1974).

[9]D. H. Rosen, D. J. Voorhees-Rosen, and R. M. Suzman, "Psychiatric Symptomatology in a Changing Shetland," paper presented at the 12th Annual Meeting of the Society for Epidemiologic Research, New Haven, Conn., June 13, 1979.

[10]In the Shetland case, for young and middle-aged women.

[11]E. J. Mishan, *Technology and Growth: The Price We Pay* (New York: Praeger, 1970), p. 52.

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[12]A. D. Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass.: Harvard University Press, 1977), pp. 3, 12.

[13]Lawrence, *Georg Simmel*, pp. 210-211.

[14]*The Birth of Tragedy*, W. Kaufmann (transl.) (New York: Vintage, 1967), section 24, pp. 136-138.

[15]Largely because so many perennial, time-consuming human activities have been technologized.

[16]On parameter variation, see W. G. Vincenti, "The Air-Propeller Tests of W. F. Durand and E. P. Lesley: A Case Study in Technological Methodology," *Technology and Culture*, 20(4) (October 1979).

[17]As in the case of its characteristic output and functions, technology can also be distinguished from science by reference to its methods. First, although scientists also use experimental parameter variation—as in the famous 1913 Geiger-Marsden scattering experiment to test Rutherford's theory "that there exists at the center of the atom an intense highly concentrated electrical charge" *(Ibid.)*—only in technology is this method used "to produce the data needed to *bypass the absence of a useful quantitative theory*, that is, to get on with the technological job when no usable theoretical knowledge is available" *(Ibid.)*. Second, the "use of working scale models . . . [is] peculiar to technology. Scientists . . . are interested in studying natural phenomena, which take place at some natural scale and have to be studied at that scale. Technologists are concerned with constructing devices that do not exist in nature, and they are at liberty to construct them of whatever size they find useful. Since the useful size for experimental study is often different from that for final application, the technologist builds scale models. The scientist does not have this alternative. Since working scale models are peculiar to technology, so also is the use of laws of similitude to apply model results to full-scale design" *(Ibid.)*. Thus technological method cannot be reduced to scientific method.

[18]See N. Rosenberg and W. G. Vincenti, *The Britannia Bridge: The Generation and Diffusion of Technological Knowledge* (Cambridge: MIT Press, 1978), pp. 6-7, 27-30. In designing the bridge, the engineers conducted experimental inquiries into the material properties of wrought iron in tension and compression, drew upon the knowledge of scale-model testing and parameter variation to ascertain the best distribution of material and arrangements of plates and rivets, and the relationship between the buckling of the flange atop the rectangular tube and the strength of the bridge. Prior to that, they concluded that, given the extraordinary length of the bridge, the stability required for a railway, and the Admiralty's requirement that the bridge must not interfere with navigation of the straits by sailing vessels, a structure of unprecedented tubular design was called for.

[19]In this instance, "the work of the civil engineer involved not the application of existing theoretical knowledge but the design and development of techniques that provided, by means of experimental investigations, empirical knowledge where theoretical knowledge was not and could not readily be made available. For example, Hodgkinson's compression tests of plates bypasses a lack of theoretical knowledge in order to establish the buckling properties of thin plates, a problem that was first studied theoretically by Bryan only forty years later" (*Ibid.*, pp. 71-72). Another example of this type of approach is dimensional analysis. These and other examples of quasi-theoretical methods are to be found within both science and technology, and in areas not clearly one or the other. They clearly show that technology is not "just applied science," not simply a matter of the application of available scientific knowledge. In sum, the growing body of technological methods and knowledge supports the important proposition that there is a significant intellectual component to modern technological activity; indeed, increasingly, intellectual character is one of modern technology's most distinguishing features vis-à-vis its nature in earlier periods. Thus, although in the nineteenth century it was unusual for an engineer to have sophisticated mathematical skills, this is no longer the case in mid-twentieth century (*Ibid.*, p. 14).

[20]D. J. de S. Price, "Is Technology Historically Independent of Science? A Study in Statistical Historiography," *Technology and Culture*, 6(4) (1965): 561.

[21]R. Chalk and F. von Hippel, "Due Process for Dissenting 'Whistle-Blowers,' " *Technology Review* (June/July 1979): 53.

[22]Committee on Social Implications of Technology, I.E.E.E., *Newsletter on Technology and Society*, no. 22 (June 1978): 3-10.

[23]Committee on Social Implications of Technology, I.E.E.E., *Newsletter on Technology and Society*, no. 24 (December 1978): 3.

[24]Chalk and von Hippel, "Due Process," p. 51.

[25]For useful background materials and interesting case studies, see R. J. Baum and A. Flores, *Ethical Problems in Engineering* (1978), available from the Center for the Study of the Human Dimensions of Science and Technology, Rensselaer Polytechnic Institute, Troy, N.Y. 12181.

[26]For a more detailed typology of (nonjudicial) governmental technology programs, for a breakdown of one category of governmental technology program—programs to encourage the development and utilization of technology in and for the private goods and services sector—in terms of how different programs in the category are targeted at different phases of the technological life-cycle, and

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for cross-national comparison of government technology policy, see J. Herbert Hollomon and Members of the Center for Policy Alternatives, M.I.T., "Government and the Innovation Process," *Technology Review*, 81(6) (May 1979): 30-41.

[27]J. G. Burke, "Bursting Boilers and the Federal Power," *Technology and Culture*, 7(1) (Winter 1966): 3. The first law regulating the steamboat industry was passed in 1838; a toughened law was adopted in 1852. "In December 1848, the [federal] commissioner of patents, to whom Congress . . . turned for data, estimated that in the period 1816-48 a total of 233 steamboat explosions had occurred in which 2,563 persons had been killed and 2,097 injured, with property losses in excess of $3 million" (p. 18).

[28]"Coping with Technology through the Legal Process," *Cornell Law Review*, 62(5) (June 1977): 817.

[29]*Ibid.*, p. 822.

[30]See R. E. McGinn, "In Defense of Intangibles: The Responsibility-Feasibility Dilemma in Modern Technological Innovation," *Science, Technology, and Human Values*, no. 29, (Autumn, 1979).

[31]L. H. Tribe, "Towards A New Technological Ethic: The Role of Legal Liability," *Impact of Science on Society*, 21(3) (1971): 218, 217, 216, 215, 221-222, 218.

[32]A. Giddens, *Capitalism and Modern Social Theory* (Cambridge, England: Cambridge University Press, 1971) p. 180.

[33]L. H. Tribe, *Channeling Technology Through Law* (Chicago: Bracton Press, 1973), p. i.

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ROBERT S. MORISON

A Further Note on Visions

PERHAPS THE MOST EMBARRASSING ISSUE to be raised by technology is also the most obvious, at least to the naive. The same youngster who noticed that the emperor had no clothes may now be asking, "What is all your technology for?" The question is embarrassing on several counts, but the most pervasive stems from the very origin of modern science and technology. Rightly or wrongly, for better or for worse, modern science and technology are regarded as having originated in Galileo's establishment of the primacy of efficient causes. Since that time no self-respecting scientist—except for an occasional embryologist and an even more occasional and deviant evolutionist—would allow himself to talk seriously in terms of final cause or purpose.

Casual conversation might loosen the rule, especially for biologists, who often found themselves surreptitiously asking what a newly discovered organ or secretion might be for. In any serious discourse, however, all science confined itself rigorously to the interpretation of current events in terms of previous ones. The future might thus be predicted, but in no way could it influence the course of events.

Not only was it regarded as philosophically unsound to invoke the future and its purposes, but there was a widespread feeling that it was rather crass or insensitive to do so. Science, like art, was pursued for its own sake, and even such advocates as Francis Bacon were at least slightly suspect for their utilitarian emphasis on relieving man's estate. Even the practically minded Faraday, who is remembered as much for the technical neatness of his experiments as for the penetration of his scientific ideas, found it necessary to turn away a philistine inquiry with his famous wisecrack about the potential taxability of one of his findings.

There was also the pervasive worry that premature interest in the purpose of inquiry or its "value" in terms of human needs or desires might contaminate the objectivity considered essential for unbiased scientific work.

In recognition of these limitations of method, and possibly with the hope of avoiding an onerous responsibility, the scientific community was only too glad to leave the value choices to those who professed to know how to make them.

For various reasons that have been widely discussed elsewhere, every one of these barriers, or self-denying ordinances, except perhaps the metaphysical one, has been eroded in recent years. Nevertheless, your average scientists and per-

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haps an even larger majority of professional technologists, whether engineers, physicians, or agricultural experts, feel uneasy when asked to discuss the purpose of what they are doing. In the event, it has been easier to begin by discussing negative purposes or costs. Positive purposes, which once seemed so obvious as to scarcely merit discussion, turn out in fact to be very difficult to characterize precisely or measure quantitatively.

Systematic discussion of particular purposes of particular technologies began in a serious way only a few years ago with the increasing consciousness that technology has undesirable as well as desirable results. This fact had always been known in a general way. Complaints about air pollution from the burning of coal go back to the Middle Ages. The undesirable side effects of new drugs were recognized by Hippocrates when he warned that, even though the occasion may be instant, the art is long, experiment perilous, and decision difficult. More recently, the notorious Luddites appeared as pioneer worriers over the effects of mechanization on job opportunities and the alienation of the worker from his work. Only in the last two decades, however, have men thought seriously about weighing the pluses and minuses of a technology in advance of actually using it. The first formal account of the need for a general procedure named technology assessment, and an outline of how it might be carried on, were promulgated in 1969 in a report from a committee of the National Academy of Sciences-National Research Council.[1] Shortly thereafter the Congress responded with the establishment of an actual Office of Technology Assessment. So far it has not assessed a great deal of technology, but its history does provide a lively and instructive view of the difficulties involved.

As is so often the case with new technologies, it was the military that first opened the road to technology assessment, with a set of procedures known then as operations analysis, or, more crudely, target selection. The criterion of choice was cost/effectiveness, which in peacetime has, with some loss of self-restraint, been converted into cost/benefit.

So far so good; all is very tidy, linear, and algebraic. But anyone even casually familiar with the literature finds that the better papers end on a plaintive note. When all the numbers are added, subtracted, correlated, chi-squared, and otherwise processed, there comes the inevitable moment of truth when someone must make some value judgments about the purposes to be fulfilled. What, after all, is a benefit? Who gets it? Is the same event beneficial to some and harmful to others? Are all lives equally enjoyable? Whether they are or not, are they all equally valuable—in the sight of God perhaps, or, more often, in the sight of an insurance adjuster or a sympathetic jury? Does the $50,000 spent in keeping a leukemia patient uncomfortably alive for a year add as much to the sum total of human happiness as if it had been spent by twenty taxpayers taking their wives to Bermuda? Is, in fact, the sum total of human happiness the item to be maximized, or should we first make sure that the least advantaged are raised to some acceptable standard before we ask for algebraic sums? Is happiness, perhaps, not the point at all? In the long history of hominids, the possibility of happiness has been perceived but fitfully and realized even more rarely. Yet the modern world seems unprepared to give preemptive status to a Romanesque cultivation of duty, an Augustinian glorification of God, a Confucian veneration of one's ancestors, or, least of all perhaps, to a Pre-Raphaelite dedication to art for art's sake.

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Until recently it would have been easy for most of us to dismiss all of this as a bundle of pseudo-questions unworthy of the attention of the tough-minded. Common sense would tell us that knowledge is better than ignorance, food better than famine, health better than illness, life better than death, mobility better than stagnation, automobiles better than horses, electric lights better than tallow candles, and so on. How could we go wrong if we simply dedicated ourselves and our technology to meeting obvious human needs?

My own hope of ending my days in this kind of blissful ignorance fell away abruptly when my brother Elting Morison wrote a deceptive little book that purported to be a brief everyman's history of American engineering.[2] The simplicity of the occasion was uncomfortably complicated by the fact that the account began with a quotation from A. N. Whitehead and ended with "Some Notes on Visions" by the author. The essence of the quotation from Whitehead may be conveyed by the following excerpt: "The business of philosophers, students and practical men today [is] to recreate and reenact a vision of the world . . . either we must succeed in providing a rational coordination of impulses and thoughts, or for centuries civilization will sink into a mere welter of minor excitements." The "notes on visions" give a brief review of past visions and the chances for finding one that will keep us from sinking deeper into the welter of minor excitements in the future. The main point for our purposes is that it does not make long-term sense to assess technology merely in terms of its short-term costs and benefits. We must attempt instead to see where it fits in some much larger framework of the future, and it is just this lack of a larger frame that modern technologists find so embarrassing. They are so very good at getting you to Paris in three hours but so very poor at telling you what to do when you get there.

Indeed, it sometimes seems that society as a whole, and, surprisingly enough, a high proportion of its young people, are unable to conceive of any vision other than the welter of minor excitements. A couple of years ago, for example, I found myself teaching a section in a course that employed my brother's book as one of its texts. Somewhat unexpectedly, my principal task turned out to be an elaborate explanation of the *very possibility* of a vision different from, let alone larger than, our present one. No passions were aroused, scarcely one drooping eyelid was raised at Henry Adams's speculation about the meaning of the impending substitution of the dynamo for the Virgin. Worse than that, it seemed impossible to explain what Matthew Arnold felt he had lost as he listened to the melancholy, long withdrawing roar of the waves that once rolled from the Aegean to Dover Beach. On other occasions, I have been equally unsuccessful in getting a class to grasp what Plato and Bacon and More, or even H. G. Wells, thought they were doing in their speculative writings about Utopias.

In groping for an explanation for this curious insensitivity to things as they might be, one is forced to wonder whether the technical preoccupation with efficient causes has infatuated a whole generation. If everything is determined by preceding events, they seem to be saying, what point is there in speculating about a different kind of future?

But the picture is not all of one color. As usual, there are internal contradictions. At the same time that we lose any clear vision of the long-term future, we become increasingly, even uncomfortably aware of our power of

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choice over the short term. Technology has not only greatly widened the span of our options, it has made choosing a necessity. Faced with declining reserves of oil and gas, we can choose coal at the risk of living in a greenhouse, or go nuclear and risk a meltdown (or two or three—the figures are not yet precise), or go directly to the sun and bear enormous capital costs.

Nowhere, perhaps, are the choices more numerous, novel, and insistent than in the field of medicine, where almost every week we hear of a new way of prolonging life or of identifying some genetic defect in time to destroy life before we become too squeamish about its personhood. For most of us, the power to choose implies the obligation to do so. Science and technology not only give us the possibility of choice, they also can tell us a good deal about the results of alternate choices. But they must always stop short of telling us what it is we really want. That is the real paradox of our time—an enormous increase in power and an almost equivalent increase in the ability to foresee the effects of power in objective terms, but a decrease in our ability subjectively to decide what we want. The pressure generated by this contradiction becomes every day more difficult to ignore.

Nowhere, perhaps, is the paradox more binding than in the area quaintly known as "national defense." Science has given us the power to destroy our enemies with unparalleled efficiency. We can pretty well demonstrate that the results will be devastating to both sides, but we remain oddly paralyzed and unable to choose between making a first strike and being the first struck. One of the difficulties apparent in both the medical and national defense examples is what might be called the seductiveness of technological detail. Peace studies and arms control groups in and out of the universities have spent endless person hours estimating megatons, defining the probable precision of multiple warheads, and defining the relative hardness of various missile sites. For a certain kind of mind, the possibilities for calculation and countercalculation are endlessly fascinating, but they may also keep us from the more important effort to analyze just what it is that separates us from the Russians or to develop a cost/benefit analysis of coexistence.

The foregoing and other possible examples seem to show that as we grow microscopically more precise, we become macroscopically more confused. In Whitehead's terms, the minor excitements seem to crowd out the possibility of a "vision of the world [to provide] a rational coordination of impulses and thoughts." It seems just possible, however, that we have begun to grope our way toward the larger questions. Although the energy problem is still largely discussed in terms of drilling more wells, stripping more seams, and "synthesizing" more petroleum substitutes, every now and then a voice may be heard asking the larger questions and seeking a different vision. Why must per capita consumption of power always increase? What do we get for it? Are we happier, healthier, or closer to some other ideal state than the Swedes, who use about half as much energy as we do, or the !Kung Bushmen, who use scarcely any nonrenewable energy at all?

It may be worth spending a moment on the !Kung, because they actually tell us a good deal about the vision of human existence that endured for a much longer time than any other. From the seventeenth century onward it has been customary to pounce on any romantic speculations about a golden age and de-

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stroy them with one stroke of Hobbes's famous aphorism about the life of man in a state of nature. It did not matter that Hobbes had no empirical evidence, or that he was primarily concerned, not with the actual conditions of life, but with elaborating a speculative political theory on the basis of a hypothetical condition of early man. However it may have arisen, the famous phrase provided an all too nasty, brutish, and short way of dismissing all those who questioned current definitions of progress. Recent work, not only with the !Kung, but also with other remnants of Mesolithic man, supplemented by studies of artifacts from Paleolithic and Mesolithic times, suggests that the life of hunters and gatherers may have been quite healthy and happy, especially in comparison to that of the settled agricultural and technologically more advanced societies that came later. Many of the early societies seem to have remained in a balanced relationship with the environment for hundreds of thousands of years. Population growth was limited not so much by the natural checks of the four horsemen as by other more subtle, possibly self-conscious means.[3]

Social life was highly organized and rewarding, and above all, there was a lot of leisure time to devote to conversation, mythmaking, and other primitive arts. This last observation reminds us that the designers of modern science-based Utopias, like the archetypical H. G. Wells, stressed the role of modern technology in freeing men and women from drudgery and enlarging opportunities for more cultivated, enjoyable, and creative pursuits. The reality, of course, has turned out to be quite different. More efficient production has been used to produce more *things* rather than more free time. As Kenneth Galbraith and many others delight in pointing out, additional effort must then be spent in getting people to want the things produced. The result is that almost all adults must work almost continuously to maintain the normal American standard of living. The fact that a higher percentage of women than ever before are in the labor force should not be taken as triumphant evidence of woman's liberation. On the contrary, even a casual survey will show that most of these women work outside the home because they need the money to buy some new thing.

The vision that has kept us going during most of the modern technological age is the one formulated in the eighteenth century by the men of reason, and expressed most articulately by Condorcet. It is, of course, an aggressively secular vision, and hinges on the proposition that man's spiritual welfare is closely linked to his material circumstances. Perfect his circumstances and you perfect man himself. The material emphasis was certainly justified in the beginning, since most things were in short supply for all except the very rich. For a considerable period, material and spiritual conditions seemed to go forward together, and in the memory of those of us who are now retired, many people believed that Western man was actually improving morally as well as physically. Indeed, I can remember reading as a boy of the rackings and sackings of the Thirty Years War, and rejoicing that I lived at a time when men had clearly progressed beyond the very possibility of such cruelties.

If the sack of Magdeburg and the devastation of the Palatinate have their modern counterparts in the bombing of Dresden and Hiroshima, and if the crematories of Auschwitz have outshone the crackling fires of the Grand Inquisitor, there is at least one respect in which man has made striking, almost unbelievable progress. His physical health is much better than it was in 1789,

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and it continues to get better all the time. Undeniably, and just as Bacon and Condorcet would have predicted, this improvement has been due to progress in technology, though much less to specifically medical technology than is usually believed. In advanced countries scarcely anybody dies from the conditions that swept away half the population before puberty in Condorcet's day. Those few who now die before passing the prime of life do so for interesting reasons, which suggest that physical perfectability does not lead inevitably to spiritual peace of mind. Accidents, homicides, and suicides are now the "captains of the men of death" in the younger decades, while the results of dietary indiscretion and addiction to nicotine and alcohol dominate the forties and fifties. These by now well-known facts are particularly curious when juxtaposed with other evidence that modern man has adopted physical health as his paramount value.

It is worth pausing a moment to consider the current worship of Hygeia, since it may come as close to a universal value or Whiteheadian vision as we have been able to get. Contemplation of its obvious limitations as an organizing human purpose may help us understand how far we are from Whitehead's requirement.

Roughly 10 percent of our national income goes to support the medical establishment, replacing the tithe that in a good society of the past went to the church that in turn took responsibility for a wider range of social and spiritual activities (including many of what we now characterize as health services). In most communities of moderate size, the local hospital or medical center outclasses the structures that house the local library, the art gallery, or the church, just as in our national capital, the National Institutes of Health outspread the National Cathedral, the National Gallery, and the Library of Congress combined. Even in our greatest institutions of learning, the medical center towers above everything else, just as the budget of the medical school dwarfs that of the other arts and sciences.

A case can be made that this primacy of health in our value system was far from accidental or simply selected for want of something better. The man who, as advisor to the senior Rockefeller, was more responsible than any other for the shape of modern medical philanthropy, the ordained Baptist minister Frederick T. Gates, had this to say at the tenth anniversary of the founding of the Rockefeller Institute for Medical Research:[4]

> I said it [medical research] is as universal in its scope as the love of God, and I now add it as beneficient in its purpose. It goes to the fountains of life itself. It deals with what is innermost in every man. For what is health? Health is happiness; mere health itself is happiness.
>
> And on the other hand . . . disease . . . with its attendant evils is undoubtedly the main single source of human misery. . . . In the Rockefeller Institute we have a great organization, nobly housed, suitably equipped, splendidly endowed, inspired with the most intelligent zeal and the noblest enthusiasm to prevent and to destroy the chief source of human disqualification and misery.
>
> For what is human progress? Ultimately it is this, just this, and nothing else—an ever closer approach to the facts, the laws, the forces of nature, considered of course in its largest meaning. Nothing else is progress and nothing else will prove to be permanent among men. . . .
>
> Do not smile if I say that I often think of the Institute as a sort of Theological Seminary. But if there be over us all the Sum of All, and the Sum Conscious—a

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> Conscious, Intelligent Being, and that Being has any favorites on this little planet I must believe that those favorites are made up of that ever-enlarging group of men and women who are most intimately and in very truth studying Him and His ways with men. That is the work of the Institute. In these sacred rooms He is whispering His secrets. To these men He is opening up the mysterious depths of His Being. . . .
>
> As medical research goes on, therefore, it will find out and promulgate, as an unforeseen byproduct of its work, new moral laws and new social laws—new definitions of what is right and wrong in our relations with each other. Medical research will educate the human conscience in new directions and point out new duties. It will make us sensitive to new moral distinctions. It will teach nobler conceptions of our social relations and of the God who is over us all.

There is, of course, something admirable in all this. There may be even something magnificent about the resolve to learn God's laws and then to use them to reverse that part of the order of nature that dooms most men to less than optimal performance, if not to a lifetime of physical suffering. But there is also something almost desperate about this preoccupation with the elimination of physical distress. It suggests that, having discovered no real reason for any existence, we will devote all our efforts to making that existence at least as painless as possible. For, like it or not, health is at base a negative concept. In the optimistic reaction that followed the horrors of World War II, the World Health Organization tried hard to promulgate a positive definition of health as a "state of complete physical, mental, and social well-being" much more than the mere absence of disease, but the idea never caught on. The most obvious reason was purely technical. Doctors are trained in terms of disease, and the elaborate machinery at their command is designed to uncover the abnormal. Health is thus usually defined as that state in which all the pointer readings fall within the normal range. In practice, that range can be very broad, and most medical people become confused and embarrassed if called upon to define a scale for measuring degrees of health. Instead, they are content to define health as an absence of obvious disease.

The second reason for the failure of positive definitions of health is more subtle and more germane to our present concern. When called upon to speak about health in positive terms, the sensitive physician suddenly finds himself struggling to define the good life, and this he feels ill equipped to do. Certainly before World War I, and even perhaps until World War II, it was possible to believe that other members of the learned world had this task reasonably well in hand.

Now one is not so sure. Certainly the secularization of life in the twentieth century explains some of the difficulty. Shorn of its traditional religious metaphors, Gates's vision simply doesn't shine as effulgently as he hoped, and it comes as something of a shock to discover that the only alternative to seeking a divine purpose is to live in such a way that all one's organ systems function according to accepted norms. If he were to return to us today, Gates might well ask if there is no way of being secular without being exclusively corporeal. Must those who followed the gleam of the grail now content themselves with a bottle of Natural Lite.

All this is not to say that health is not a desirable state nor that it is a mistake to include it among the three wishes placed before the good fairy, but its proper

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status is that of a means, not an end itself. Just as there is something a little sad about a man who buys a new car simply because he wants to wash and polish it every Saturday morning, there is something quite wrong about a man who jogs five miles before breakfast, eschews bacon and eggs, and turns down a stressful but interesting job, all because he is obsessed by the need to remain in "good health." Actually, good health is not even an indispensable means, as the lives of many poets, musicians, and even soldiers remind us. One might even ask if a Dostoevsky who enjoyed good health could possibly have written *The Brothers Karamazov*.

Perhaps the most uncomfortable aspect of health as an end is the way it substitutes or obscures the need for more mature approaches. Thus it has come to dominate many aspects of our national life where in other cultures it might seem only distantly related.

The health theme is central to much of our advertising, some of it directed at specific aches and pains or the suppression of odors, but a considerable proportion directed at establishing less well-defined states of well-being, like the mystical unions cemented by daily libations of Geritol. Medical research has long been recognized as the keystone to better health, and the budget for health-related research is second only to that for research related to national defense, which many of its proponents may think of as health-related also. Indeed, ever since the Rockefeller boards decided to concentrate on health as the root of most of man's evils, a major part of private philanthropy has been channeled into the improvement of health in various ways.

Perhaps most revealing of the way in which health has taken over or underlies the whole contemporary value system is best seen in the way the health theme is used to justify other values and purposes. Thus most of the standards set for cleaning up the environment are related to real or fancied effects of pollution on human health. True enough, many environmentalists have their own quite different sets of values that prompt them to take an interest in returning the environment back to its pristine condition. Some of them are doubtless moved by aesthetic considerations: the San Bernardino mountains do look better on clear days, and salmon leaping in uncontaminated rapids are a more cheerful sight than the green scum floating on a stagnant, eutrophic pool.

Others are consciously, or perhaps unconsciously, embarrassed by the primacy God is said to have given Western man in the Book of Genesis. As a result, they feel a moral urge to come to the defense of more endangered species. Some of the most ardent are certainly closet pantheists, possibly unaware of their addiction to an outmoded heresy and unwilling or unable to expose it to public view. All too rarely but significantly, courage and wit may sometimes combine to ask such questions as "Should trees have standing?"[5]

All these alternative attitudes and values have a need to be explored and considered in their own right. In practice they are all subordinated to the health theme, because in our present state of grace this is the short route to the most votes.

Even the values attached to nature by former generations of religious and literary figures must now be interpreted in terms of the health needs of some people for solitude, fresh air, or the tonic effect on the heart of a rainbow in the sky.

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Perhaps the most serious result is the way the preoccupation with health occludes the search for other ends. Even though one suspects that other ends may never be found, the renunciation of the search leaves us with nothing to do but order up another angiogram to assess the heart's desire, or to prescribe the most recent tranquilizer to still the remnants of existential angst.

It remains only to mention some of the other and perhaps more serious external costs of placing a disproportionate value on health. These have been most comprehensively and unrestrainedly dealt with by Ivan Illich. Unfortunately, the richness of his rhetoric, the radical conservatism of his distorted remembrance of things past, and the often flagrant misinterpretation of the numerous citations with which the text is so proudly burdened have served to turn attention away from the important core of truth in *Medical Nemesis*.[6] As I understand it, and stripped of its distracting conspiratorial interpretation of the medical profession, an account of his position might run something like this:

> For various reasons, not the least of which is its apparent success in reaching limited objectives, modern medical technology has achieved enormous prestige and influence in our society. This has led, among other things, to a vast erosion of the individual's reponsibility for his own health and welfare and to its transfer to health professionals. Thus the professionals originally charged with the prevention and control of disease become increasingly responsible for new types of illness and disorders. Of the three classes of iatrogenic sicknesses Illich describes, the social illness is perhaps the most interesting and relevant to our present concern.

The point here seems to be that the human community lost a good deal of what made social life worthwhile, or warm or rich or human, when it adopted a very limited definition of normal behavior and regarded all departures from this norm as illnesses to be cared for by professionals. Prominent among his examples are aging and death, and certainly there is now a very rich literature describing the need to deprofessionalize the care of these two inevitable parts of natural man's existence. Psychiatrists like Szasz and Laing have extended the same sort of thinking into the realm of so-called mental illness, and there is a growing effort to reduce the number not only of the mentally ill, but also of the mentally retarded that must now be cared for by professionals in institutions. But here again we encounter a difficulty. Wise though it may be to give up measuring some of these people on the sickness-health continuum, the unhappy fact of the matter is that many do not adjust easily and well to twentieth century urban living.

What is clearly needed is a system of social values that includes a place for those different, but not necessarily unhealthy, people. Our present tendency to overemphasize health as a value and at the same time to define the unusual as pathological may thus unduly restrict the scope of our social arrangements.[7]

In conclusion, it appears that technology assessment is even harder than we thought. It is not enough to judge a given technology in terms of how effectively it realizes its stated objective and how well it avoids undesirable side effects and external costs. The very value system or "vision of the world" within which the technology is to function must also be taken into account.

The relationship is a reciprocal one. A comprehensive, satisfying vision of the future, if we had one, would provide an overall standard by which to judge

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the more obvious and immediate purposes of our technological advances. It would give substance to such currently nebulous concepts as the "quality of life" or the "integrity of the environment" that we now call upon as substitutes. It is this function that I believe Whitehead had in mind when he wrote the sentences that constitute the theme of this paper.

As we also have tried to show, a particularly brilliant technology may give a spurious brilliance to an inadequate vision. Means tend to become ends in themselves, and the search for a more enduring purpose is slowed down or forgotten. At its worst the inadequate substitute value system may tempt us into superficially satisfying, but in the long run deleterious, solutions to social problems. Indeed, as we have tried to show, there is some evidence that the primacy currently given to health as a value has unduly limited our sense of responsibility for the environment. Similarly, in our relationships with one another, the tendency to regard deviations from accepted behavioral norms as deviations from health may set too narrow a limit to our social arrangements and responsibilities.

To take a perhaps more familiar but quite different example, that of a premature satisfaction with inadequate visions, one may speculate that our society might be in better shape today if it had not been too ready to believe that the early material successes of the spirit of capitalism were the outward and visible signs of inward and spiritual grace.

References

[1]National Academy of Sciences, *Technology: Processes of Assessment and Choice* (Washington, D.C.: U.S. Government Printing Office, 1969).

[2]Elting E. Morison, *From Knowhow to Nowhere: The Development of American Technology* (New York: Basic Books, 1974).

[3]Richard Lee and I. DeVore (eds.), *Man, the Hunter* (Chicago: Aldine Press, 1968); Brian Spooner (ed.), *Population Growth: Anthropological Implications* (Cambridge, Mass.: M.I.T. Press, 1972); James V. Neel, "Lessons from a Primitive People," *Science*, 170 (November 1970): 815-822.

[4]For more about Gates, see his recently published autobiography: Frederick Taylor Gates, *Chapters in My Life* (New York: The Free Press, Macmillan, 1977). More of the cited address is quoted in George W. Corner, *A History of the Rockefeller Institute, 1901-1953* (New York: Rockefeller Institute Press, 1964).

[5]Christopher D. Stone, "Should Trees Have Standing?—Toward Legal Rights for Natural Objects," *Southern California Law Review*, 45 (7): 450.

[6]Ivan Illich, *Medical Nemesis: The Expropriation of Health* (London: Calder and Boyars, 1975).

[7]For an unusually thoughtful and objective appraisal of current controversies growing out of the tendency to consider a variety of social issues under the rubrics of health, see Renee Fox, "The Medicalization and Demedicalization of American Society," *Daedelus*, Winter 1977, p. 9. Incidentally, mention in the present article of the views of Szasz et al. does not imply that I do not believe that there are real biologically based illnesses that profoundly alter human behavior. It is the uncritical extension of this concept to other deviations, the origin of which is still unknown, that may constrict our vision of the good society.

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HARVEY BROOKS

Technology, Evolution, and Purpose

IT HAS BEEN TRADITIONAL to define technology in terms of its physical embodiments, as novel physical objects created by man to fulfill certain human purposes. In my opinion, this is too limited a view and one that is becoming increasingly obsolete. Nevertheless, this narrow conception of technology is perhaps one source of the current malaise with respect to technology and our technological society.

Hannay and McGinn have said that the "basic function of technology is the expansion of the realm of practical human possibility."[1] This is a good definition, but it seems to me that it already implies a good deal more than physical artifacts. Technology must be sociotechnical rather than technical, and a technology must include the managerial and social supporting systems necessary to apply it on a significant scale. Most highly original inventions have usually involved social as well as technical innovation. The Edison electric light, the Xerox copier, the computer, the Polaroid camera, the automobile, the television system—all involved concepts of complete technological systems that included supporting organizations and markets. In the case of TV, very different managerial and financing systems grew up in different countries with the same hardware building blocks. To be sure, not all innovations are of the sociotechnical system type. Many are simply components that fit into existing systems, such as magnetic bubbles or integrated circuits, and their introduction requires little social or market innovation. Ultimately, however, even such purely "hardware" type innovations can have major social impact through the changes they make possible in the systems of which they are a part. Other innovations may arise largely out of basic scientific discoveries such as lasers and many new materials.

In the past, the social aspect was largely restricted to the market, to envisioning a social need not previously imagined to exist that could be so marketed as to create a self-sustaining technological system. In this sense, many of the most important inventions have been systems inventions in which the organization of the market has been part of the system. Today, managerial innovations are becoming an increasingly important aspect of technology. We see this particularly in the case of computers and communications systems, where not only the software, but also the organization that goes with the system, are inseparable from the physical embodiment of the technology, and are often the most expensive and innovative parts of it. Some enterprises such as MacDonald's or the

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supermarket are based almost entirely on managerial innovation, with simple inventions in hardware being added gradually and later as incidental improvements to the original managerial concept.[2]

It seems to me that the defining feature of technology is that it is "public knowledge," in the sense proposed by J. M. Ziman with respect to science.[3] But rather than knowledge of how and why things are as they are, it is knowledge of how to fulfill certain human purposes in a specifiable and reproducible way. The characteristic aspect of public knowledge is its communicability and reproducibility; it is something that can be reconstructed in principle through specifiable algorithms.[4] To an extent, it is independent of culture and can be reproduced in any culture. Yet, not all cultures are equally receptive to it, and the process of assimilation may require great effort and patience. Furthermore, different cultures will tend to generate or select different technologies, so that the actual technological system that is chosen will be culture-dependent. Technology, therefore, does not consist of artifacts but of the public knowledge that underlies the artifacts and the way they can be used in society. Management, insofar as it can be described by fully specifiable rules, is thus a technology, and indeed every large bureaucratic organization can be considered an embodiment of technology just as much as a piece of machinery. Thus it has been suggested that the greatest innovation in the Apollo program was not the hardware, but the managerial system. This system made possible the degree of reliability and technical discipline necessary to bring the project to a successful conclusion, through the coordination of the activities of hundreds of contractors and subcontractors.[5] In contrast, the report of the Kemeny Commission suggests that it was the lack of similar mangerial innovation in the nuclear industry that led to the mishaps of Three Mile Island and Brown's Ferry.[6]

By identifying technology with knowledge rather than artifacts, we do not intend to imply that technology is the same as science, or even that it is based on science, which is conceptual knowledge involving mental models applicable in a large number of concrete situations. Technological knowledge can be highly scientific and abstract, but it can also be highly concrete and empirical. Usually it consists of a mix, with the science component being much larger in the technologies of more recent vintage. It is also important to observe that the process of creating technology for the first time is quite different from the process of specifying it so that it can be reproduced by others. The creation process is culture-dependent, but its reproducibility makes it technology rather than art.

The assertion that technology is culture-*in*dependent is, of course, controversial, but it is certainly true that most cultures behave as though this were so. The attitude toward Western technology in Islamic cultures is particularly interesting in this respect. Even a country as conservative as Saudi Arabia believes it can adopt modern technology while retaining all the essentials of Islamic culture and beliefs. Japan is often cited as an example of a different culture that has assimilated modern technology and become a creator of it without giving up its own cultural norms. That this is questionable does not alter the fact that the transferable elements that specifically define technology are not part of culture. The social effects of technology are secondary consequences of living with the embodiments of technology, not a part of the technology itself. This is true even if the social consequences turn out to be inevitable for practical pur-

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poses. We know, for example, that people of widely differing political, cultural, and religious persuasions can both create and apply the same technologies.

The Innovation Process

The process by which technology is conceived, developed, codified, and deployed on a large scale is called innovation. In fact, it is its reproducible and transferable nature that makes it possible for technology to be diffused widely, often with surprising speed. We know today that innovation is the major source of economic growth in industrial societies, almost certainly more important than physical factors such as labor and capital.[7] Indeed, growth probably occurs primarily as a result of the embodiment of new knowledge both in physical capital and in human labor and organizations. In this sense, innovation consists in the creation of sociotechnical systems, and it is these systems that are the source of economic growth.

Because of the relationship between the creation of technology and economic growth, industrial societies have become increasingly preoccupied with diagnosis of the innovative process in order to stimulate and nurture it as a source both of domestic growth and comparative advantage in international trade.[8] In addition, it has become an ever larger component of military power; indeed, the capacity of the United States to innovate rapidly and efficiently in weapons systems is frequently put forward as the key source of continuing U.S. military advantage over the Soviets, offsetting their greater rate of investment in military hardware during the past decade.[9] Since the early 1970s, increasing concern has been expressed in the United States about an alleged decline in our rate of innovation, especially in comparison with the dynamic economies of Germany and Japan.[10] The U.S. trade deficit and declining rates of growth of productivity in the domestic economy are attributed in part to declining innovative capacity. However, there is little agreement as to whether the declining innovation rate is a problem in itself or a symptom of other changes in U.S. society, such as a low savings and investment rate and an increasing shift of both innovative effort and investment toward environmental improvement, energy savings, and social services. The product of these improvements is not measured in customary productivity indices, but it may be of equal or greater value from the standpoint of overall social welfare.[11]

Innovation is not the same thing as either R&D or invention, although these are both important parts of the innovation process. The process includes the evolution of a whole technological system, from research through invention, to design for manufacturing, and marketing or operational application. As indicated earlier, innovation includes organizational change and the creation of social support systems to make possible the deployment and use of artifacts on a large scale. Thus the system of service stations and repair shops, of highways and highway maintenance, of credit and insurance, of traffic controls and law enforcement, all comprise the technological system of automobile transportation. Their creation constitutes a part of the innovation process in which the automobile is the central artifact.[12] In this sense, we see that innovations are not conceived and created all at once, but, rather, that they evolve in close interaction with society. Very often the driving force may be the central artifact—in

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our example, the automobile—and this pulls along with it a host of ancillary technologies, from gasoline pumps to oil refineries to radar speed measuring devices. One can, in fact, imagine a variety of alternative organizational and supporting systems embracing the same basic technological elements. For example, the automobile system could have developed entirely on a rental rather than an ownership basis, much like the telecommunication system.

Most innovations are directed not at the final consumer, but at the development of capital goods and intermediate products that are inputs to the manufacturing process or the distribution system. These innovations affect the consumer only indirectly through their influence on the costs of production and distribution. They may also interface with the public through their effect on the environment or public health.

The fact that most innovation is directed at capital and intermediate inputs is the reason that labor productivity, or factor productivity more generally, can be used as measures of the rate of technological change. Innovation directed at the final consumer, by contrast, often does not show up in Gross National Product measures. For example, home appliances that have enormously increased the productivity of work in the household, or power tools that have increased the productivity of do-it-yourself work, hardly show up at all in conventional measures of GNP or productivity. Only the tools and appliances themselves, not the continuing stream of services they provide, are valued in the GNP. Similarly, new products or processes that reduce pollution or save energy have become an increasingly prominent target for innovation, yet are measured only minimally in the GNP. An auto tire that has a much longer lifetime or that results in substantial fuel savings over the life of a car will be counted in the GNP only to the extent that it is more expensive than the tires it replaces. This extra initial cost, however, will generally be more than offset by lower sales of replacement tires and by fuel savings over the lifetime of the car. Thus, the net effect of such an innovation could be a reduction of measured GNP, even though society is obviously materially enriched by its substitution for older products.[13]

In the past, a very dynamic area of innovation has been that of materials with new properties, ranging from high-purity silicon fabricated into integrated circuits to high-strength alloy steels. Yet, these material innovations result almost exclusively in intermediate goods that are sold to manufacturers either to improve production or to be incorporated into capital goods or consumer goods. New materials have often made goods cheaper and more durable, as in the replacement of vacuum tube radios and TV by solid state electronic devices that are both cheaper and longer lasting. Here, again, we see an important package of innovations that does not show up directly in measures of economic output or personal consumption. They may affect GNP, but only indirectly, by reducing the cost of final goods, and thus generating increased purchases through the mechanism of price elasticity of demand, or simply because the goods are more attractive to consumers.[14]

It is often useful to think of biological evolution as a metaphor for technological evolution and innovation, although technological evolution takes place a million times faster than biological evolution.[15] In this metaphor the part of genetic inheritance is played by the inherent logic of technological develop-

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ment, whereas the part of natural selection by the environment is played by the social mechanisms of decision, including the market. Just as other species form part of the environment that exercises selection pressures on a given species, so do competing technologies form part of the selective environment that determines the evolution of a given technology. Technologies have ecological relationships with one another, and occupy ecological niches in the overall technological system, as do species in the biological world. The biological metaphor is most apt in the case of markets, where selection is exercised in millions of decentralized and uncoordinated decisions. It is less clearly applicable when society exercises collective choices, as, for example, in the case of political decisions to go forward with or cancel large technological programs such as the SST or the breeder reactor. Social decisions to regulate environmental impact, or occupational health and safety, similarly have no clear counterpart in natural biological evolution, except in the sense that they are culture-dependent and thus part of the social context of technological evolution.

The biological analog of conscious political choice in technological evolution is, perhaps, best viewed as analogous to the artificial selection used in creating domesticated species. Here, man has intervened in natural selection to produce new biological results that are the product of conscious collective choice. Just as man has learned how to direct natural evolution in parts of the ecosystem through artificial selection, so have societies gradually learned how to take over the direction of technological evolution from the market through collective regulation or government investment. In this sense, the art of technology assessment becomes analogous to the art of plant or animal breeding. The possibilities for the channeling of technological evolution are still constrained by the internal logic of technology at a particular stage of its development, just as the possibilities for creating new properties of plants and animals are constrained by the varieties that exist in the present generation and by the laws of genetics. One can, perhaps, carry the analogy still further by pointing out that the modern phenomenon of organized innovation in large firms and laboratories may bear some resemblance to a kind of genetic engineering in the biological field.

The biological metaphor is useful because it illuminates the debate between those who see technology as proceeding inexorably by an inner logic and those who see technology and innovation as being largely driven by social forces or class interests. Just as the genetic variations on which natural selection acts are determined by internal genetic events, so evolution from one generation of technology to the next is determined by logic internal to the technological system. But just as the number of genetic variations is very large compared with the number that are propagated in the next generation as a result of natural selection, so is the number of technical possibilities very large compared with those that actually survive in the development process, and even more so in the market or society. Thus the influence of society and culture on the inner logic of technology is similar to the influence of the environment on genetic inheritance between successive generations. In each case the inheritance mechanism produces a large redundancy of possibilities, while the environment selects those that survive to the next generation. In technological evolution, what survives provides the knowledge base that generates the full range of possibilities for the next generation of technology. The genealogy of ideas in the evolu-

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tion of technology is similar to the genealogy of genetic variations in biological evolution.

Some of the critics of recent technological trends argue from perspectives somewhat similar to those who are critical of human intervention in natural evolution, as in the use of artificial monocultures in modern intensive agriculture. Just as ecologists deplore man's upsetting of the "balance of nature" through his agricultural and building or industrial practices, so some critics of recent technology argue that consumer sovereignty no longer controls its development; technology, rather, is forced into the market by high-powered sales techniques and by the influence of concentrated corporate power on the political process. These critics would agree that the biggest revolution in the last half century is the development of systems for the organized generation of new technology, the creation of institutions to manufacture new technology in almost the same way that in the nineteenth century we created institutions to manufacture and market goods and services on a large scale. But it is exactly this revolution that they condemn as taking technology out of the context of "natural" evolution in the marketplace.[16] Only in the days of the lone inventor was the evolution of technology truly "organic," allowing the social selection process time and trial-and-error to determine the true "fitness" of a new technology. By contrast, today's "artificial selection" or forced development of technology is creating "monsters" that are vulnerable and nonresilient.

It is interesting to note, in fact, that this criticism emanates in different ways from both the Right and the Left. The Left sees the generation of new technology as having been taken over by concentrated corporate power in alliance with government, especially the military; the Right sees the evolution of technology as being increasingly distorted by political intervention and the creation of perverse incentives by government. Neither, however, usually condemns the same end results of technological evolution. Critics of the Left focus their condemnation on large-scale technologies, especially military development and large-scale energy generation technologies such as nuclear power; critics of the Right, on the diversion of technological innovation to meet what they see as unreasonable environmental requirements or health and safety regulations. Nevertheless, some critics on the Right have asserted that nuclear power has run into trouble just because it was forced prematurely into the market through government pressures on industry and special economic incentives that distorted the form and rate of evolution of the technology.[17] Industry, they say, was led down the primrose path by government. In two other respects the critics would probably agree: that government regulation has given a comparative advantage to larger firms, and that it has tended to erode competitiveness in the economy.[18]

Recent Trends in Technological Development

What can we say about recent trends in the character of technology? To what extent are these trends inherent in technological logic; to what extent are they a product of social forces; and to what extent are they merely transient phenomena as compared with irreversible tendencies? Just as biological evolution has often led to dead ends, is it possible that technological evolution is leading us into cultural dead ends, as the critics of the New Left maintain?

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Is technology the cause for, or the solution of, the *problematique* of our newly global society, or is it some combination of both?[19]

Following are analyses of a number of trends or alleged trends and attempts to diagnose their future course.

SCALE Economies of scale have been a major driving force in the evolution of technology in the twentieth century. These economies apply both to the size of individual embodiments of technology—supertankers, nuclear power plants, wide-bodied aircraft, energy and communications networks—and to the size of the market for consumer technologies—automobiles, TV and radio, pocket computers. The scale of markets, of course, implies an accompanying large-scale sociotechnical system for marketing and service, so that it equally requires large organizations and control systems. There is some evidence that we may have come to the end of the road as far as the scale of individual technological embodiments are concerned. In the past decade, for example, no additional economies of scale have been realized with electric generating plants, and there is even some indication that the reliability of such plants is lower than for smaller plants. Political difficulties in the siting of power plants have increased rapidly as the scale of individual plants has increased, in part because of the concentration of environmental impacts. Even though the cost of pollution control tends to be a smaller fraction of plant cost as size increases, the environmental impact is more concentrated, and hence visible, and tends to provide a more obvious target for opposition.[20] Supertankers have become so large that they can enter fewer and fewer ports, and will be subject to ever tighter navigation restrictions. Ecological damage from the shipwreck of one supertanker is more obvious and concentrated, even though such tankers account for only a small fraction of the oil entering the marine environment.

Many environmental problems are associated not with new technologies *per se* but with the scale on which they are applied and diffused. Individually, automobiles are less polluting and place smaller demands on natural resources than did the horse-and-buggy. Electric generating plants pollute the air less than wood stoves relative to the amount of energy produced. Traffic and congestion are problems of scale, not of the basic building blocks of technology. Some of these problems of scale arise because a particular technology tends to become less adaptive to its environment as its scale of application increases: designs become standardized in order to realize economies of scale, making it more difficult to adapt designs as environmental problems resulting from this same scale become manifest. Technological evolution, which is highly plastic and responsive in its early phases, tends to rigidify as a result of its market success.

Yet, scale is a complex concept, and not all trends are in the direction of centralization. When examined carefully, the concepts of scale and centralization become rather ambiguous. The automobile, in its individual embodiment, is a decentralized technology that permits much more personal control over mobility than does public transit. Indeed, when the value of time is taken into account, the automobile appears to be the cheapest form of transportation in most circumstances. Other small-scale technologies that facilitate personal control and choice are home appliances, television, phonographs, personal computers, telephone services, and credit cards. From the standpoint of the user, these

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seem to be "appropriate technologies"' in most of the senses usually put forward by the advocates of such technologies. Yet, they are seldom cited favorably, apparently because all require enormous production, distribution, and service networks that are associated with centralization and bureaucracy. The booming do-it-yourself home tool and shop business, cable TV, citizen's band radio, self-powered camping vehicles—all are technologies that appear to increase individual control, without depending very much on large centralized infrastructures. Individual solar energy installations are frequently cited as an example of appropriate technology that frees the individual from dependence on impersonal energy networks; yet, it is hard to see how solar energy could be deployed on a significant scale without standardization and mass production, and without large distribution and service networks differing little from those associated with, say, automobiles or home appliances.[21] The advocates of decentralized energy systems often envision a do-it-yourself construction and repair industry, but, in this case, massive education and information dissemination would be necessary, even assuming most families would want to build their own. Clearly, this is a prime example of Spreng and Weinberg's trade-off with both time and information.[22]

CENTRALIZATION AND DECENTRALIZATION The automobile and cable TV may be examples of two decentralized technologies that have displaced or will displace centralized large-scale technologies. The automobile has already largely displaced the passenger railroad and urban mass transportation in most of the United States. It has done this by making possible decentralized living patterns (associated also with the availability of home appliances) and by introducing, through competition, diseconomies of small scale into public transportation. Public transport has the characteristic that both the quality and the cheapness of the service improve rapidly with increasing patronage. But patronage of rail and public transit is declining everywhere in the industrialized world, and we see a descending spiral of poorer service and further loss of patronage.

It could well be that we will see a similar phenomenon occurring between broadcast and cable TV and, even conceivably, between solar energy and centralized electric grids. Cable TV could well draw off the most affluent patronage from broadcast TV, thus setting off a spiral of declining advertising revenue and ever poorer programming, which could result in the demise of "poor man's" home entertainment, just as the automobile threatens the demise of "poor man's" public transportation. Similarly, the advent of decentralized power sources, available at first largely to the more affluent, could so degrade the economics of energy distribution networks as to make them uneconomical or inordinately expensive without public subsidy, such as is now necessary to sustain public transit.

These examples show that the trend toward centralization in modern technology is less clear and less certain than is sometimes asserted. Many modern technologies are, in fact, decentralizing rather than centralizing, much as in the case of TV in comparison to the movie theater of a generation ago.

STANDARDIZATION One of the ways to achieve economies of scale has been through standardization of products, especially in the basic technology. This standardization is now appearing on a world scale through dissemination by

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enterprises that transcend national boundaries. One hears, for instance, increasing talk of a "world automobile."[23] We have seen that the widespread use of small-scale decentralized technologies requires standardization in production and service aspects if the technology is to become inexpensive enough to be accessible to a large fraction of the population. Thus, even for decentralized "appropriate" technologies, it is the form of centralization that is changed rather than the need for centralization in some aspect of the system.

The advent of sophisticated and cheap information technology may also be greatly decreasing the significance of standardization for achieving economies of scale in production and distribution. Assembly systems can now be programmed to turn out many individualized versions of a technology on the same production line, and this is probably only the beginning of a trend toward substituting cheap information for standardization. Indeed, following the argument of Spreng and Weinberg, the old-fashioned mass-production factory was a device for economizing on both time and information in the production process; but as information becomes cheaper, it is no longer so necessary to economize on it in order to obtain an inexpensive product accessible to all. Production can be much more individualized, even crafted. Similarly, in the distribution process, the ability to store information has made it possible to reduce inventories and to offer wider choices to consumers. In the servicing of products, the replacement of mechanical by electronic functions should have two effects: to make products more durable and to make diagnostics and repair much more automatic, hence, cheaper. Thus one impact of information technology may be to change the economic balance between cheap capital-intensive production and expensive labor-intensive repair that has been the underlying driving force of our "throw-away" society. This change will come about because repair will be cheaper and materials and energy that go into the original production more expensive.

LABOR VERSUS ENERGY AND MATERIALS An important characteristic of technological progress in the last one hundred years has been that it is labor-saving (or time-saving) rather than materials- and energy-saving. Although outputs per unit of labor, material, and energy input have increased, the output per unit of labor has increased much more rapidly than the other two. This is a consequence of the fact that the cost of labor has risen much faster than the cost of materials and energy, and it is thus logical that a major part of technological innovation should be directed at saving on the most expensive input. A man-hour of labor today buys many times more raw materials and energy than it did in 1900.[24] Indeed, until the early 1970s, the trend in real costs of energy and raw materials had been almost uniformly downward for more than a century.

While there are few experts who would agree that we have reached "limits to growth" in terms of basic materials and energy, or that we will "run out" of the resources necessary to support continued economic growth within the foreseeable future, there *is* general agreement that resources will become more expensive, and that we are entering a period of transition from a world economy based on the extraction of cheap resources from localized, high-grade locations, to an economy based on the extraction of more abundant but much lower grade, and hence more expensive to extract, resources that are more widely distrib-

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uted.[25] This transition will involve, as well, extensive substitution for relatively rare and expensive resources—as it were, substituting information (and ingenuity) for unusually, but only temporarily, accessible resources. What this implies, of course, is that much more innovative effort in the future will be directed at saving resources and energy, or substituting more abundant, but more difficult to convert and use, resources for relatively rare, but easier to convert and use, resources.[26] Natural gas and oil are prime examples of resources that are remarkably easy to extract and use; they will be replaced by coal, uranium, and solar energy, all of which are more abundant and widely distributed, but much harder and trickier to convert to usable form. But in the intermediate term there is general agreement that the most cost-effective policy is to extend the life of our highest-quality resources through investments in more efficient end use.[27]

A question difficult to answer is whether the shift of innovative effort toward materials and energy conservation will result in slower growth of labor productivity. There is evidence of a trend in this direction in the United States, but there is no consensus that this has much to do with a shift of innovative effort. Some attribute it to emphasis on meeting environmental restrictions, but the question still appears open at present.

There is little question, however, that the entrepreneurial opportunities in technology for energy and materials efficiency are very large. This is especially true because the new technologies associated with the word "microelectronics" have very high potential for substituting ingenuity (information) for materials and energy consumption. A major part of the recent improvement in fuel efficiency of automobiles has been due to the use of electronic techniques in controlling combustion. The possibilities of using sophisticated controls on the direction and flow of energy in industrial processes and in commercial and residential use are great and have barely been started. Of course, microelectronics can also replace human labor; to the extent that higher energy costs are reflected in increased wage inflation, there may be equal pressures to use technology to replace labor. But it may also be that here is an opportunity to channel consciously an emerging technology into applications that are preferentially resource-saving rather than labor-saving, and this may require more than normal market forces to make it come about. At all events, this appears to be a prospective sea change in the direction of technological progress in the future.

CONSUMER SOVEREIGNTY VERSUS COMPLEXITY To the degree that the products of innovation go directly to the consumer, rather than being sold as intermediate goods or capital equipment to producers, they have been characterized by an increasing mismatch between the complexity of the product and the ability of the purchaser to assess its qualities and performance. Thus the traditional model of the market in which producers and consumers bargain rationally, based on complete information regarding the properties of the products in question, breaks down. To be sure, various countervailing mechanisms have arisen—consumer research organizations, consumer protection legislation and agencies such as the Consumer Products Safety Commission, stricter product liability interpretations in the courts, and voluntary industry standards. All of these mechanisms are intended to substitute for the lack of knowledge and time

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for the consumer to evaluate the host of products he buys. Where the balance now lies, therefore, can be endlessly debated without any clear conclusion.

In the nineteenth century *caveat emptor* was the rule, and the purchaser of a defective or hazardous product had little recourse other than not to purchase the product a second time. But products were also much simpler and fewer in number and variety. The question today is whether the countervailing mechanisms have kept up with the increased complexity of products. This question applies not only to issues of safety, but also to matters of durability, maintainability, energy consumption, and environmental effects, none of which can really be assessed by the consumer before he buys. In the courts, the burden of proof has shifted strongly toward the producer to prove the safety and performance of his product. For high-technology products, such as prescription drugs, an elaborate assessment mechanism has been created to protect the consumer, despite the fact that the physician is an intermediary between the producer and developer of the drug and the patient. This is because the technical sophistication of the product is beyond the capacity of even a professional who is not a specialist on pharmaceuticals to evaluate.

Of course, the inability of the consumer to properly evaluate high-technology products has led to the centralization of decision-making with respect to the safety of such products. Organizations such as the Food and Drug Administration, the Consumer Product Safety Commission, the Automobile Safety Administration, and the Federal Trade Commission intervene between producer and consumer. Even for producer goods, such as manufacturing machinery, the Occupational Health and Safety Administration has intervened to protect the worker. Products such as passenger aircraft, nuclear reactors, public transportation equipment, and residential and commercial buildings are all subject to evaluation by public intermediaries on behalf of the safety and health of the consumer.

In summary, while the increasing complexity of products has led to the erosion of consumer sovereignty as a mechanism for quality control and product assessment in the market, substitute intermediary mechanisms have evolved for making such decisions in a centralized way on behalf of the consumer. These mechanisms, however, constitute another source of centralization and bureaucratic structures that have been generated by modern technological trends.

ENVIRONMENTAL POLLUTION AND EXTERNALITIES There is a widespread public perception that technology has increased the pollution of the environment, and multiplied the hazards to the health and safety of the public that arise from the deployment of technology. This perception may be only partially correct. The rising public and scientific concern is not yet matched by statistical indicators that show life is more hazardous on the average than it used to be. Quite the contrary is the case.[28] With the exception of the rise in the incidence of lung cancer, which is generally acknowledged as attributable mainly, if not exclusively, to smoking, there are no trends in the incidence of specific forms of cancer that suggest the appearance of a major new threat to human health. Certain other forms of cancer, such as melanoma, have shown increases in incidence, but are statistically minor in the overall picture. Some diseases thought

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to be environmentally caused—notably cardiovascular diseases—have shown improving trends in the United States within the last few years.

However, all this does prove that technology may not present a latent hazard that has not yet caught up with us. New substances are constantly being introduced into the environment, and new technology deployed in such a way that a major commitment is often made in a period that is short compared with the induction period of cancer produced by low-level exposures to environmental contaminants. Our knowledge of the biological mechanisms of cancer induction is too rudimentary for us to rule out such future delayed effects from current industrial activities. There have been numerous examples in which occupational exposure to chemicals, or exposure of patients to new drugs, has resulted in serious delayed effects. The cases of asbestos and vinyl chloride monomer come to mind, as well as several examples of mercury poisoning. Fortunately, the population affected has been sufficiently small so that these episodes have not affected national health statistics. But the potential is there. In the case of saccharin, for example, more than seventy million people routinely use saccharin, and the rate of saccharin use among children under ten has risen dramatically within a few years.[29] With such large populations exposed, even very minute cancer risks could result in a large number of people being affected in decades to come. Hence, the concern and debate over whether saccharin should be banned. Fatigue failure of man-made structures is something that can occur after many years of use; it represents another example of a delayed effect that could appear long after an apparently safe technology had been deployed on a large scale. Fortunately, we know a good deal more about the physics of metal fatigue than about the biology of cancer induction, but the possibility of hazard is there. The recent problem with the DC-10 is a sobering reminder.

Alterations of natural ecosystems can also have human effects that are long delayed and may not be felt until future generations.[30] The intergenerational question has been raised especially forcefully in connection with radioactive waste management from the nuclear power industry. The effect of fluorocarbons from spray cans on stratospheric ozone is a worry only many decades in the future, but it will result from current activities and take many decades to disappear even after the use of fluorocarbons is banned.[31] The increase of carbon dioxide in the atmosphere as a result of burning fossil fuels and the conversion of forests to agriculture is another essentially irreversible, but long-in-the future, effect.[32] Thus the absence of contemporaneous indicators of trouble is not cause for complacency.

Another source of concern is that, whereas earlier environmental threats could be apprehended by the senses (for example, smoke), or had an immediate effect (disease due to contaminated water), today's hazards of technology can often be identified only with the aid of very sophisticated science. They usually have to be measured with sensitive scientific instruments, and their human effects lie at the end of a long, complex, and frequently uncertain causal chain, as in the case of fluorocarbons or sulfate aerosols from coal-fired electric power plants.

Innovation for What?

Until World War II the process of technological change was largely directed by the market. Only in the military field was it clearly driven by other forces,

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but until the postwar period the magnitude of military R&D and the rate of military innovation were modest compared with civilian fields. In 1938 agricultural research constituted 40 percent of all government-supported research in the United States. By the mid-sixties it had dropped to 1.6 percent. In 1938 federally supported research constituted less than one-sixth of national R&D expenditures. In the mid-sixties it was nearly 70 percent, and it has fallen off to about 45 percent today.[33] During the postwar period technological development has also been increasingly driven by new technological opportunities, as perceived in the political process—civilian nuclear energy and the space program are among the clearest examples.

Within the last decade increasing attention has been given to the collective channeling of technology to realize certain social goals outside the purview of the market. The biomedical research program of the National Institutes of Health and rising expenditures on energy and environmental research are here the clearest examples. Environmental regulation has also played an important technology-forcing role in the private sector, as illustrated by the dramatic growth of research expenditures by the automobile industry in connection with emission controls and fuel conservation. More precisely stated, regulation has created a market for technologies that would not have been demanded by consumers because their benefits represent a public good—for example, pollution controls. Nobody has made an accurate estimate of what fraction of the national R&D effort, private and public, is now directed at meeting goals established by government through regulation or by citizens through collective action in the courts.

We do know that in the last two decades the percentage of technical articles published in *Science* that deal with risk assessment has increased eightfold, and this is certainly symptomatic of a broad trend in scientific and technological activity and interest.[34] Despite all this, however, the overwhelming proportion of nonmilitary research is still directed at meeting traditional market demands, directly through innovations in consumer products, and indirectly through advances in manufacturing or service technology or in the materials and components used in consumer products and capital goods.

Robert Morison's paper raises the issue of whether this laissez faire (or *laissez innover*) approach to technology is appropriate under modern circumstances.[35] Much of today's R&D, it is argued, is aimed at extending or elaborating the amenities available in already affluent societies. These may represent improvements in the quality of life that are marginal at best, and that may be increasingly offset by unforeseen side effects a little further in the future. The question raised is whether technology can and should be directed in a more concentrated way at meeting fundamental human needs of the future.

In the eyes of many, humanity is at a crossroads, on the threshold of a precarious future that could bring catastrophe and collapse or material abundance for all. This "transition crisis" arises because many of man's activities are now of sufficient magnitude to make significant inroads on the natural world we have inherited from geological ages. For the first time we are depleting some of the mineral concentrations laid down over geological history. Several natural geochemical cycles of nitrogen and of sulfur are now being appreciably accelerated by man's activities, and we have the capacity to accelerate many others, such as the hydrological cycle, in the near future. We are now changing the

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trace substance composition of the global atmosphere sufficiently to alter climate drastically early in the next century. Agriculture now accounts for about 5 percent of all photosynthetic fixation of carbon, and the burning of fossil fuels similarly corresponds to 5 percent of the global carbon fixation rate.[36]

What are the fundamental human needs to which advances in science and technology could contribute? They are the standard list: food, energy supply, health, a cleaner environment, materials supply, transportation, shelter, personal security, and a social system that facilitates rapid adaptive change while containing the possibility of violent conflict. The achievement of a minimum level for all people in each of these areas is for the first time within reach from a technical and scientific viewpoint, although science and technology cannot provide a solution by themselves. They only generate the conditions in which society can develop a solution.

Should or can science and technology be channeled toward providing a minimum standard in each of these areas for every living person? I start from the premise that such a standard is technically attainable; not everybody would agree. The existence of absolute poverty in the world can no longer be justified as a result of the scarcity of resources or the lack of technical capacity to alleviate it. This is also an important respect in which we are at a crossroads: ours is the first generation in which the technical possibility of a materially secure future can be envisioned concretely without implausible extrapolation from existing knowledge.[37]

Socially and managerially we may not be able to manage the transition. It might, for example, entail a sacrifice of other values that are too cherished in advanced industrial societies to be given up willingly. A central argument of antinuclear activists, for example, is that safe and secure management of a global nuclear power industry would inevitably entail infringement of civil liberties.

Continued economic growth is most frequently attacked on the grounds that it destroys environmental values, which are cherished more for their own sake than for their biological or physical sustenance of human existence.[38] Legal philosophers debate seriously whether objects of nature should have "standing" in the courts in the same sense as young children or other helpless people who cannot defend themselves.[39] Whether the plight of the poor in the world can be alleviated without some sacrifice of these values is at least open to question. Those who defend them most earnestly argue that the problem of poverty should be solved by redistribution rather than growth, but it is hard, for me at least, to believe that the proponents of this view are really serious.

Improvement of the material condition of mankind inevitably involves *some* redistribution, of course, even if it results mainly from economic and technological growth. Such items as land and wilderness are in finite supply, and thus tend to become increasingly shared in one way or another.[40] In affluent societies the most privileged groups can no longer command the personal services of others to the degree possible in poor societies. One suspects this may be one of the unconscious reasons the condemnation of economic growth is confined mainly to an affluent minority in such societies. The redistribution that has taken place is not so much in income or wealth (though rich countries generally have much more equal income distributions than poor ones), but in what wealth or income can command. The poor can buy TV sets and automobiles, but the rich can no longer buy personal services or privacy.

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What is implied by the foregoing, then, is that, although science and technology have provided us with the means to overcome scarcity for everybody, it is less than self-evident that the actual application of these means is compatible with such other goals as democracy, personal liberty, an aesthetically satisfying environment, the preservation of pristine nature, or individual privacy and dignity. These, of course, are culturally derived values, and the culture is certainly part of the environment that selects future technology. Also, the personality types that emerge in various technological systems are different, and may in fact be contradictory with the character types we idealize and regard as "civilized" in the best sense.

Perhaps the greatest fear of some critics of technological societies is not that progress will destroy or eliminate these values and character types, but that, if they do, we will not even miss them. At all events, it seems to me that this is where the central debate on "innovation for what?" lies. Is the society of material abundance for all, which is within our reach from a technical point of view, a society that we want? The problem is, those who have not attained to the state of the affluent countries seldom consider that there is a real choice. They want material progress; they are willing to mitigate the social costs only to the extent that this does not interfere with progress. If the materially most advanced societies decide that they have had enough of material progress, and look to other values, they may not be able to arrest the process of change at the present level. The rest of the world may simply sweep over them in its demand for what the advanced societies have already achieved.

The other problem is, of course, that innovative capacity is largely concentrated in the advanced societies and is mostly concentrated on the problems and aspirations of those societies, whereas the objectives of innovation are increasingly related to the poor societies. Some objectives, of course, are to some extent common, energy supply perhaps being the best example. But even here needs may be different and technologies not directly transferable.

We have learned that innovative capacity is the hardest thing in the world to transfer. Technology *can* be transferred, because, as we have seen, the very definition of technology implies transferability in some degree, even though the receptivity of a different culture may be in doubt. But innovative *capacity* may be much more culture-dependent. One of the characteristics of all innovation (as opposed to research or development *per se*) is that it can only be carried to closure in very close relationship to the final user of the technology. Even in developed societies many innovations fail because in the end they don't quite "fit." This problem is compounded when we try to innovate in a society at one cultural and material level for the benefit of another society at quite a different level. Indeed, several participants at the conference that led to this volume have severely condemned the whole notion of innovation *for* someone else. Yet, if the world cannot make use of the innovative capacity that already exists, but has to wait for the development of indigenous innovative capacity in an almost autonomous or self-sufficient fashion, it may be too late for the transition. There are some promising developments, although it is too early to say how they will finally turn out. During the past eight years the international agricultural research system, with its network of independent but cooperating institutes, has grown to be extraordinarily effective, especially in innovating close to the ultimate user. An increasing number of developing countries show signs of having

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crossed a sort of take-off threshold of economic development, although the revolution in Iran illustrates how precarious this transition can be. The next decade will be critical in relation to a host of developments in the application of technology to economic and social development. It is unclear whether crises like that in Iran will be a common feature of rapidly developing societies, especially those with non-European cultural traditions, or whether rapid economic development can follow a relatively smooth path. I remain an optimist because of my belief that man will not be foolish enough to reject what is within his grasp, and that we will succeed in reconciling further material progress with the other values we hold dear.

REFERENCES

[1]This volume of *Daedalus*.

[2]Levitt, Theodore, "Management and the 'Post-Industrial' Society," *The Public Interest*, 44 (Summer 1976): 69-103.

[3]Ziman, J. M., *Public Knowledge: The Social Dimension of Science* (New York: Cambridge University Press, 1968).

[4]Brooks, H., "A Framework for Science and Technology Policy," Arleigh House IEEE Workshop on Goals and Policy, 2 (5) (November 1972): 584-88.

[5]Sayles, L. A., Chandler, M. K., *Managing Large Systems* (New York: Harper & Row, 1971).

[6]Kemeny, J. G. (ch.), *The Need for Change: the Legacy of TMI*, Report of the President's Commission on the Accident of Three Mile Island, October 1979, USGPO.

[7]National Science Foundation, Science and Technology Annual Report to the Congress, August 1978, USGPO, 1978.

[8]The White House. Fact Sheet. The President's Industrial Innovation Initiatives. October 31, 1979.

[9]Perry, R., Long, F. A., Reppy, J., "U.S. Programs Military R&D: An Introductory Overview," and "R&D American Style," prepared for Cornell/Rockefeller Workshop on Decision-Making for U.S. Programs of Military R&D, March 1-2, 1979 (to be published).

[10]Katz, M., (ch.), *Technology, Trade, and the U.S. Economy*, report of NAE Workshop, Woods Hole, August 22-31, 1976, Office of Foreign Secretary, NAS, 1978.

[11]Brooks, H., "Science and the Future of Economic Growth," *Journal of the Electrochemical Society*, 121 (2) (February 1974): 35c-42c.

[12]NAS, *Technology: Processes of Assessment and Choice*, Committee on Science and Astronautics, U.S. House of Representatives, July, 1969, USGPO, pp. 16-17.

[13]Heller, W., "On Economic Growth," in Schurr, S. H. (ed.), *Energy, Economic Growth and the Environment*, published for Resources for the Future, Inc. (Baltimore: Johns Hopkins University Press, 1972), pp. 3-29.

[14]Brooks, H., "Applied Research: Definitions, Concepts, Themes," in *Applied Science and Technological Progress*, Committee on Science and Astronautics, U.S. House of Representatives, June 1967, USGPO, pp. 21-55.

[15]Brooks, H., "Technology Assessment as a Process," *International Social Science Journal*, UNESCO, 25 (3) (1973): 247-56.

[16]Wald, G. and discussants Bell, D., Brooks, H., and Fisk, J. B., "Man and the Machine: Prospects for the Human Enterprise," in Greenberger, M. (ed.), *Computers, Communications, and the Public Interest* (Baltimore: Johns Hopkins University Press, 1971), pp. 255-93.

[17]Bupp, I. C., Derian, J. C., *Light Water* (New York: Basic Books, 1978).

[18]Ginsburg, Douglas H., Abernathy, W. J. (eds.), *Government, Technology, and the Future of the Automobile* (New York: McGraw-Hill, 1980).

[19]Brooks, H., "Technology: Hope or Catastrophe?" *Technology in Society*, 1 (1979): 3-17.

[20]Brooks, H. "The Energy Problem," *Oak Ridge Bicentennial Lectures, Technology and Society*, sponsored by Oak Ridge National Laboratory, 1977, pp. 101-19, ORNL/PPA-77/3, USGPO, No. 060-000-0081-6.

[21]Brooks, H., "Critique of the Concept of Appropriate Technology," *Appropriate Technology and Social Values—A Critical Appraisal*, Long, F. A. and Oleson, A. (eds.), published for the American Academy of Arts and Sciences (Cambridge, Mass: Ballinger, 1980).

[22]This volume of *Daedalus*.

[23]Orski, C. Kenneth, "Urban Transportation: The Role of Major Actors." Address delivered at the Aspen Conference on Future Urban Transportation, sponsored by the American Planning Association, June 3-7, 1979.

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ELECTRONIC REPRODUCTION PROHIBITED

[24]Rice, D. B. (ch.), *Government and the Nation's Resources*, report of the National Commission on Supplies and Shortages, Washington, USGPO, December 1976.

[25]Brooks, H., "Notes on the Energy Problematique," prepared for IFIAS Seminar "From Vision to Action," held in Mexico City under auspices of El Colegio de Mexico, October 22-26, 1979 (to be published).

[26]Brooks, H., "Resources and the Quality of Life in 2000," *Annual Review of Materials Science*, 8 (1978): 1-19.

[27]Brooks, H., Hollander, J. M., "United States Energy Alternatives to 2010 and Beyond: The CONAES Study," *Annual Review of Energy*, 4 (1979): 1-70.

[28]Kates, R. W., "Assessing the Assessors: The Act and Ideology of Risk Assessment," *Ambio*, 6 (5) (1977): 247-52.

[29]NAS/NRC, *Saccharin: Technical Assessment of Risk and Benefits*, part 1^F, Committee for a Study on Saccharin and Food Safety Policy, Assembly of Life Sciences, NAS-NRC, 1979.

[30]Brooks, H., "Environmental Decision-Making: Analysis and Values," in *When Values Conflict*, Tribe, L. H., Schelling, C., and Voss, J. (eds.), (Cambridge, Mass: Ballinger, 1976), pp. 115-35.

[31]Tukey, J. W., et al., *Halocarbons: Environmental Effects of Chlorofluoromethane Release*, NAS-NRS, September 10, 1976.

[32]Charney, J. (ch.), *Carbon Dioxide and Climate: A Scientific Assessment*, Summary report of an Ad Hoc Study Group on Carbon Dioxide and Climate, Woods Hole, July 23-27, 1979, National Academy of Sciences (to be published).

[33]Bush, V., et al., *Science, the Endless Frontier*, a report to the president on a program for postwar scientific research, July 1945, republished by the National Science Foundation, July 1960, cf. table 1, p. 86.

[34]Kates, R. W., "Assessing the Assessors."

[35]This volume of *Daedalus*.

[36]Stumm, W. (ed.), *Global Chemical Cycles and Their Alterations by Man*, (Berlin: Dahlem Konferenzen, 1977).

[37]For a striking presentation of this perspective, see Marchetti, C., *On 10^{12}: A Check on Earth Carrying Capacity for Man*, Research Report RR-78-7, May 1978, International Institute for Applied Systems Analysis, Laxenburg, Austria.

[38]Tribe, L., "Ways Not to Think About Plastic Trees," in *When Values Conflict*, Tribe, L. H., Schelling, C. and Voss, J. (eds.), (Cambridge, Mass: Ballinger, 1976), pp. 115-35.

[39]Stone, C. D., "Should Trees Have Standing?—Toward Legal Rights for Natural Objects," *Southern California Law Review*, 45 (1972): 490.

[40]Brooks, H., "Environmental Decision-Making."

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W. O. BAKER

Science and Technology

THE CONNECTIONS BETWEEN SCIENCE AND TECHNOLOGY have become increasingly strong in the modern era of systems development and application. And systems development and use are nowadays the principal way the public encounters innovation and, in turn, forms its attitudes toward research and discovery.[1] Accordingly, in dealing with the issue of how science and learning can serve our people and, through engineering and development, advance our economy, we should seek a common systems language, or at least meanings, of how we handle—that is, create and apply—science and technology.

Word Meanings in Science and Technology

Unfortunately, the meanings are already complicated by long established designations such as "industrial research." In an operational sense, this is partly a contradiction in terms. This is because effective scientific research, highly self-driven and individualized, eludes much of the institutional and managerial influence that is the essence of skillful industrial technology, systems development, and innovation of these times. "Basic research" is a suitable term connoting new science.

Yet, popular views, encouraged by the media and parts of our educational system (and, one must say, even some elements of the professional community), espouse the realism of direct conversion of scientific discovery and concept into goods and services for an eager marketplace. In the latter, such innovations may sometimes be linked with the social problems of environmental pollution, dietary disease, occupational hazard, and so on that lead to the issues of overregulation and economic stagnation. Hence occurs the growing confusion that science, even outside its part in nuclear and other weaponry, is dangerous; that is, that knowledge is a hazard. But it is actually the given technical system (transport, food, health care) that has to be qualified, not the scientific components that may go into it.

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Industrial Roles of Science

Thus our opening statement that science and technology are evermore closely joined certainly is not meant to say that it automatically, relentlessly, happens that way. On the contrary, we are suggesting that only by special strategies should we expect new science to be a major participant in useful innovation occurring through industry today. The present (inadequate) status of energy technology and the ineffective efforts at systems development in that compelling matter provide abundant evidence for our view.

Accordingly, while on the one hand science and technology are expected to provide personal, social, and economic gains, or are accused, on the other, of causing trouble in modern civilization, we must try to understand what processes actually lead to technological innovation.[2] Conversely, what scientific impacts may be incurred in measures to avoid technology, or prevent it, in order thus to have some influence, if not control, over its occurrence? Parts of the technical process involving discovery, indeed the application of science, but also the creation of new scientific knowledge in an industrial context, are the concerns of this essay. First, as we have said, the notion that significant basic research can be accomplished in a specific industrial focus already committed to a particular course of development, and therefore that such research will smoothly and steadily lead from new science into the mission technology, are widespread misconceptions. We believe, however, that there are strategies that, on the basis of decades of experience in their use, seem to permit a systematic coupling of basic science and industrial technology. However, this process is much rarer than is assumed or even taken for granted by policymakers in government and elsewhere. For instance, we are already struggling to make this happen in the National Cancer Program, and have barely begun to have the issue recognized in trying to organize a national energy effort.

Before pursuing these matters in detail, we should comment on innovation today, as it is evolving more and more into a systems effect. In this way, we shall have the best chance of gaining common meanings and concepts of the uses of interlinking science and technology.

Innovation for industry has earlier followed paths that we would now call invention and application of new *components*. Thus, Sir William Perkin's work on coal-tar dyes fitted the pattern of a traditional and historic industry of textiles and colors. The early work on rayon, and more recently on the families of synthetic fibers, was long adapted to traditional textile processing and cloth usage. Similarly, antibiotics and other admirable chemotherapeutic agents were generally created for specific uses in which, again, the total systemic role was ignored or unknown (as dramatized by thalidomide). The design of automobiles to resemble horseless carriages is frequently cited as an example of component invention and innovation in which the idea of a system of transportation remains obscure (and is perhaps even a minor factor in today's technology!). The laser is a modern example of a new component, but many other elements are required to comprise a lightwave communications system, as indicated in Figure 1.

However, certain industries were forced from the beginning to deal with elaborated systems of technology because they had no historical framework of operations to begin with. Also, they could not depend on natural resources—

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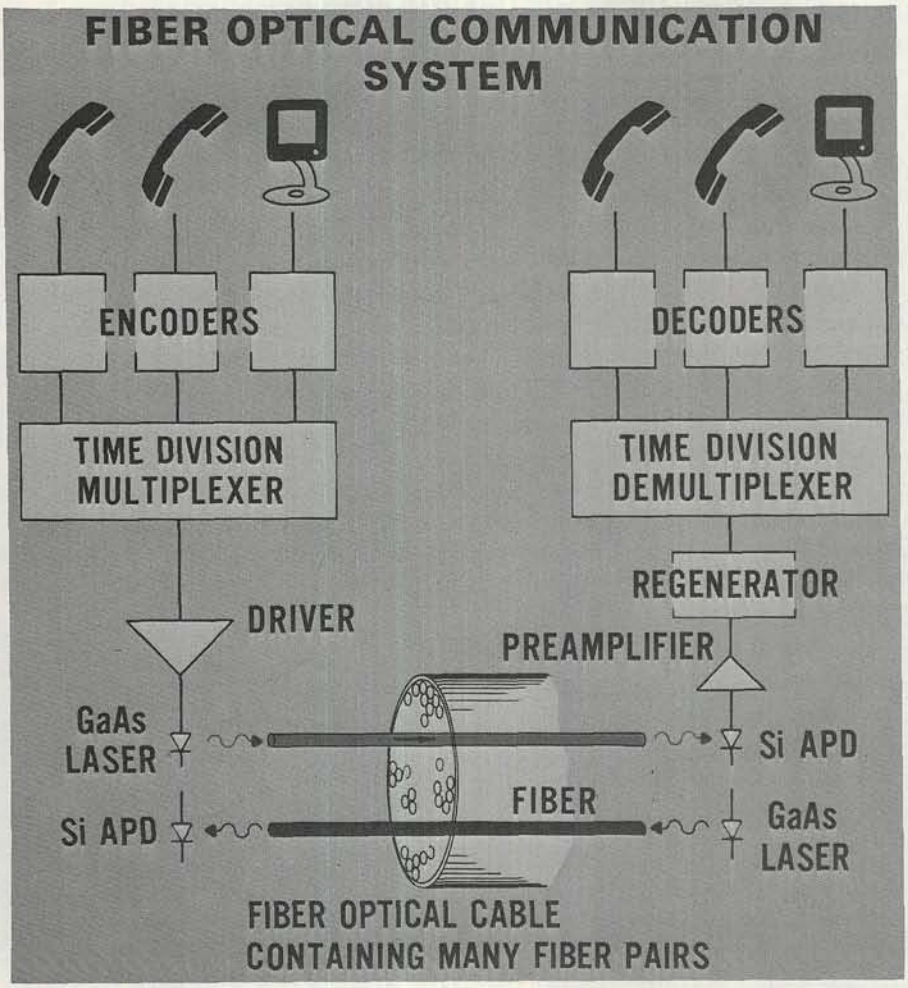

Figure 1. The laser, a new component in telecommunications systems, is shown here in a lightwave communications system.

dyes, medicinals, fuels, minerals—for major products. These industries have developed various forms of *systems engineering* that provide overall technico-economic guides to the assemblies of components on which the industry depends. These systems parameters provide an ongoing set of scales for innovation, and point to the general regions of challenge to which research as well as development can most suitably be related. For instance, a telecommunications system requires a transmission medium to carry the signals. The efficiency of various media appear as parameters in Figure 2.

Familiar cases of such industries now include telecommunications, computers, and automata, and, as a special "public service," aerospace. But it appears that strategies on which they depend can also be progressively applied to materials-based industries and to a wide range of new service functions, generally designated as health care, education, and recreation. Particularly, the emer-

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gence of materials systems engineering bears heavily on environmental and ecological factors (mining, petrochemical operations, construction, and so on), and is an especially demanding arena for technical innovation.

Systems Engineering and Systems Science

Examples of how these features of systems analysis and modeling, especially by the use of modern automata, can help in optimizing innovation through research and development (R&D) will be given.[3] Although there will always be a strong role for Edisonian methods and fortunes, the essential opportunism intrinsic to all discovery seems to be much aided by appropriate systems insights. Further, the social interface—the level of human needs and desires for a product or service—is best recognized economically and technically in terms of the suitable system. This is especially so in the new modes of deriving technology from basic science.

An examination of issues in technology and innovation usually covers pervasive matters of policy, funding, technological assessment, markets, governments, and social impacts, among many features. But yet a different feature is becoming prominent in the age-old history of invention and discovery—beyond

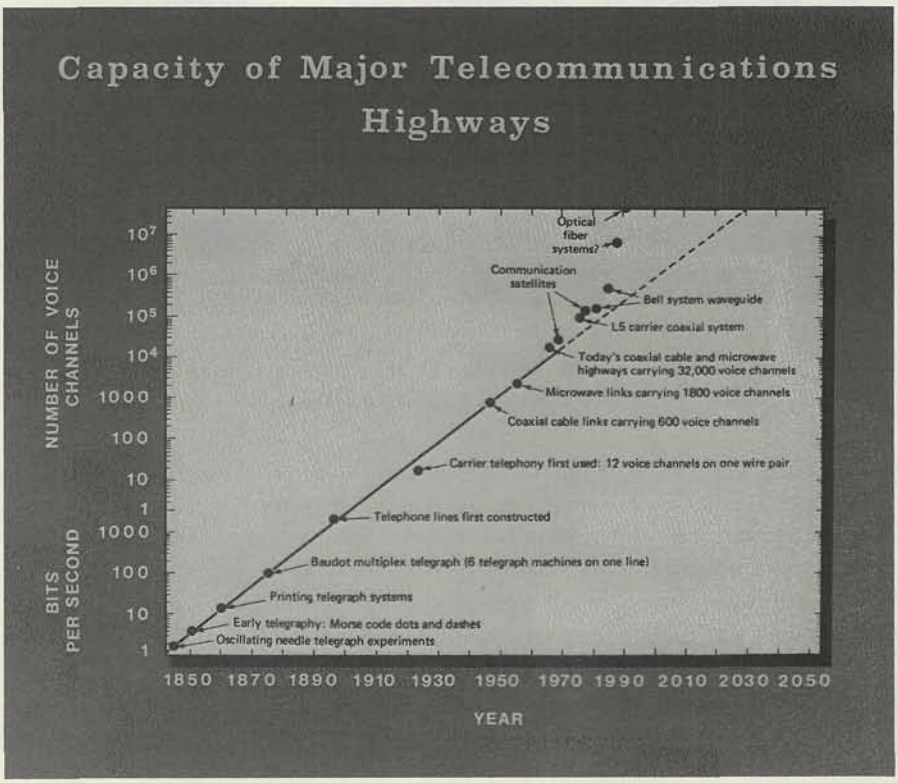

Figure 2. Capacities (actual and projected) of various media used by telecommunications systems from 1850.

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the wheel, the lever, or, in America, the typewriter in 1867, the telephone in 1876, the airplane in 1903, xerography in 1938, or even the ballpoint pen of the same year. These all denoted a great phase of technology that is slowly, but steadily, being joined by a different one—a role of basic science. Namely, in the cases we have cited, human needs or social wants or individual enthusiasms did give special and often decisive stimulus to these inventions and innovations. Thus, modulation of those subjective qualities would presumably influence, or at least be guiding factors in, technology.

But then this new element emerged, such as Faraday's ideas about electric motors and magnets, and Joseph Henry's about inductors and signaling systems, Roentgen's findings of X rays and radiograms (1895), and Marconi's observations on radio waves (1898). Then, at an accelerating pace, Fleming's identification of penicillin (1929), Lawrence's design of the cyclotron (1931), Stibitz's electrical digital computer (1937), and so on, to nuclear chain reactions by Fermi and others (1942), the Bardeen-Brattain-Shockley transistor (1947), and the laser and maser by Townes and Schawlow (1958) all mark shifts to a new guide for technology. This is, of course, science, in which an orderly search for, and accumulation of, understanding (indeed, ends in themselves in the saga of civilization) have also been adapted to become major resources for technology. This has been a slow and tortuous course, pursued primarily in a few industrial laboratories, although it was strongly accented in military programs of the mid-century such as radar, missile guidance, sensors, and nuclear weaponry.

Thus it has also been found in recent decades that not only are scientific discovery and insight essential for a large part of modern technology, but that systems science is a necessary ingredient. That is, as we shall see, it is no longer sufficient (although altogether necessary) to have the discovery of a transistor or a silicon logic diode to assure the spread of telecommunications and automata. Nor does the discovery of the laser (Figure 3) by itself produce an era of photonics, in which guided lightwaves perform all the signaling and control functions previously made possible only by radio or metallic conductor networks.

Rather, the classic episodes of specific scientific insight—quantum theory for the behavior of particles and waves, group theoretic concepts for the structure and dynamics of solid crystals, the Newtonian mechanics of celestial bodies, including earth satellites and space ships—all of these have to be appropriately associated with the interrelated effects. These can then eventually be brought together in the form of a digital machine based on integrated electronics, or a video display system, or, increasingly, even the relationship of a computer-assisted tomographic identification of a malignant tumor (Figure 4), whose resulting irradiation dosage is carefully controlled as a function of the neoplasm's three-dimensional position and surroundings in the body.

Technical Direction with Scientific Basis

We shall examine presently further examples of this issue of generating and even guiding new technology through its scientific origins. But evidently, also, the question of the feedback effect needs to be remembered. And beyond that must be emphasized the constant need for this new science. It must reach into details denoted not only by the familiar and potent driving force of curiosity of

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the individual researcher, but also into questions perceived by many more—characteristically, about an order of magnitude more—workers who are developing and applying. This vast new population (the national total of 625,000 scientists and engineers in R&D to be reached in 1980 includes about 90,000 in universities and 60,000 in the federal government; the 475,000 in industry are primarily in technology) is often lumped for convenience by the press and popular feelings into a category of "industrial and governmental scientists." It is not, as we have said, pursuing basic science, but is increasingly capable of using it in various sophisticated forms.

The Case of Surfaces

A fascinating example of a strategy linking science and technology in this community has been the evolution of surface science of solids, particularly in relationship to electronics and microcircuitry. Surfaces have received keen attention during this century as the site of much important chemical catalysis (indeed, resources by which modern hydrocarbon automobile fuels are synthesized). They also have been studied by Tabor and others for their frictional and other dynamic features. But these investigations have been largely empirical. Surfaces of solids were long viewed as too complicated, too undefined, for really scientific study.

Of course they had some specific technological properties of special import, such as, in the case of cathode ray tubes, the source of the electrons from the heated cathodes. Interest in this matter had led Davisson and Germer to discover the wave/particle nature of electrons through their interest in the structure of these emitting surfaces. This finding, in the first quarter of the century, was a cogent reminder to us that we had better seek new access to the understanding of surfaces, at least in our industry. Indeed, as vacuum tubes and cathode rays declined in use (they still are the essence of all electronic display systems including, particularly, television), we were moving into technologies where we would have to live with surfaces for the foreseeable future. These ranged all the way from plain fabrication of equipment with adhesives, and the insulation of conductors and other electrical members with films of synthetic polymers, to the early realization that the transistor effect, the behavior of p-n junctions, and a host of other features of solid state science were dependent on surface properties. This is all in addition to the original concepts of Bardeen and his associates that surface states in semiconductors determined much device behavior.

Now arises the issue of how, and how much, effort can be supported in seeking a new scientific base for what the wisdom and taste of the scientific community has said is unsuitable for basic research. We have already reported, in various contexts, our answer to this matter, which is, that champions have to be found first. These champions must be talented persons, persons not easily discouraged, but not bullheaded or fanatical either. They must have, above all,

Figure 3. Bell Laboratories researcher uses a pair of tunable picosecond dye lasers to study the ultrafast electronic response of semiconductor surfaces.

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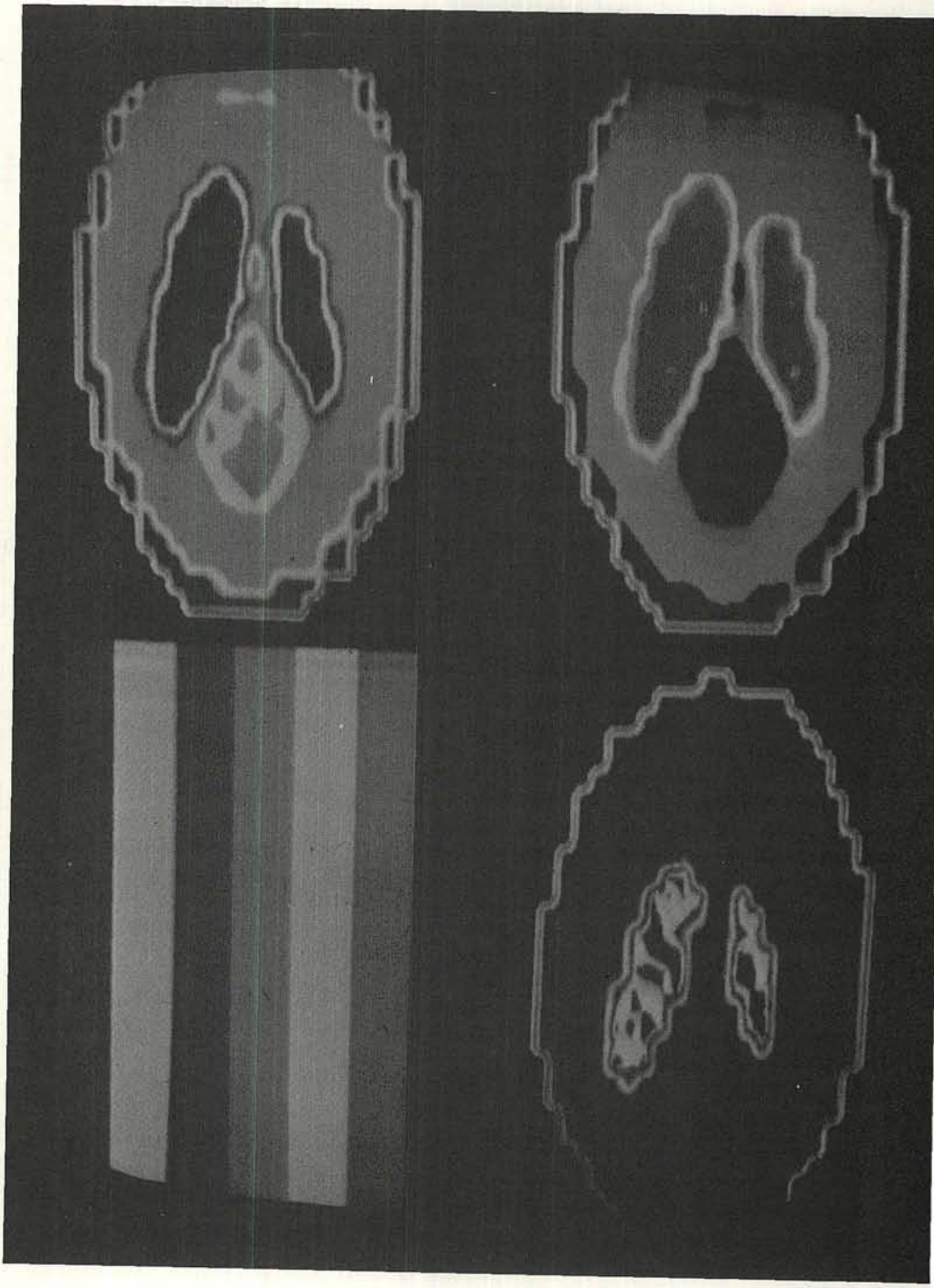

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intellectual talent and the conviction that a scientific method properly equipped can enhance knowledge, no matter how whelming the complexity. Even to find such persons requires a relatively large community, intimately acquainted with each other. In general, the potential champions would already have set up a competency, probably in some more conventional field, well recognized and critically accepted not only by the local community, but also by the larger world grouping of their peers.

But this is only the beginning, even if such unusual human resources are found. For then, interactions and opportunities must be conceived and identified by which the new and risky venture into complexity is able to build on, and to expand through, still broader bases of other science, which is in its turn leading to other technology. Indeed, the establishment of new phases of the science of surfaces, under the leadership of Homer Hagstrum and his associates, and with the support of S. Millman, A. M. Clogston, C. Herring, and others in Bell Laboratories, has illustrated in the past couple of decades just these effects. An examination of how this has happened will bear on our overall principle of how modern technology and innovation are shaped by a sufficient breadth of scientific base. Such technologies are thereby aided in meeting the increasingly demanding and even frustrating qualifications of markets, regulators, consumers, governments, environments, and ideologies to which they are increasingly subjected.

Let us recall, for instance, what lack of enough scientific aid can mean. This is seen in some of the most damaging examples of mishandling and misunderstanding of operations/engineering in recent times. These cases of surface behavior involve especially the corrosion of metals (that is, the electrochemical thermodynamics in the presence of oxygen and water, two of the most prevalent environmental factors on earth). Particularly in the United States, our railroads, the rails themselves, bridges, highway overpasses, and specific structures like New York's Westside highway have been destroyed by failure to deal with the bases of electrochemical oxidation of iron and its alloys. The wanton and mindless addition of electrolytes such as salt during the cold season is destroying major resources in urban America, including even the masonry and reinforced concrete foundations of buildings, power and communication cables under the streets, and other precious and expensive facilities. Yet, increasingly well-known and accessible scientific limits of exposure of these structures should be worked into standard technology as well as steadily applied to simple and valuable methods of protection. Indeed, suitable scientific knowledge of corrosion, of rusting and decay, can even modulate an American myth: that the free-market forces of competition will intrinsically lead to appropriate rust-proofing of our products such as automobiles. On the contrary, in this case, economic losses by corrosion are steadily increasing as a drain on our national product.

Here we have come to a case right at the center of national issues. It is clearly to the strong advantage of our people to reduce corrosion and the surface

Figure 4. In this computer-assisted tomograph (CAT), a computer reconstructs X-ray data from a three-dimensional object, such as the human brain, to help identify malignancies.

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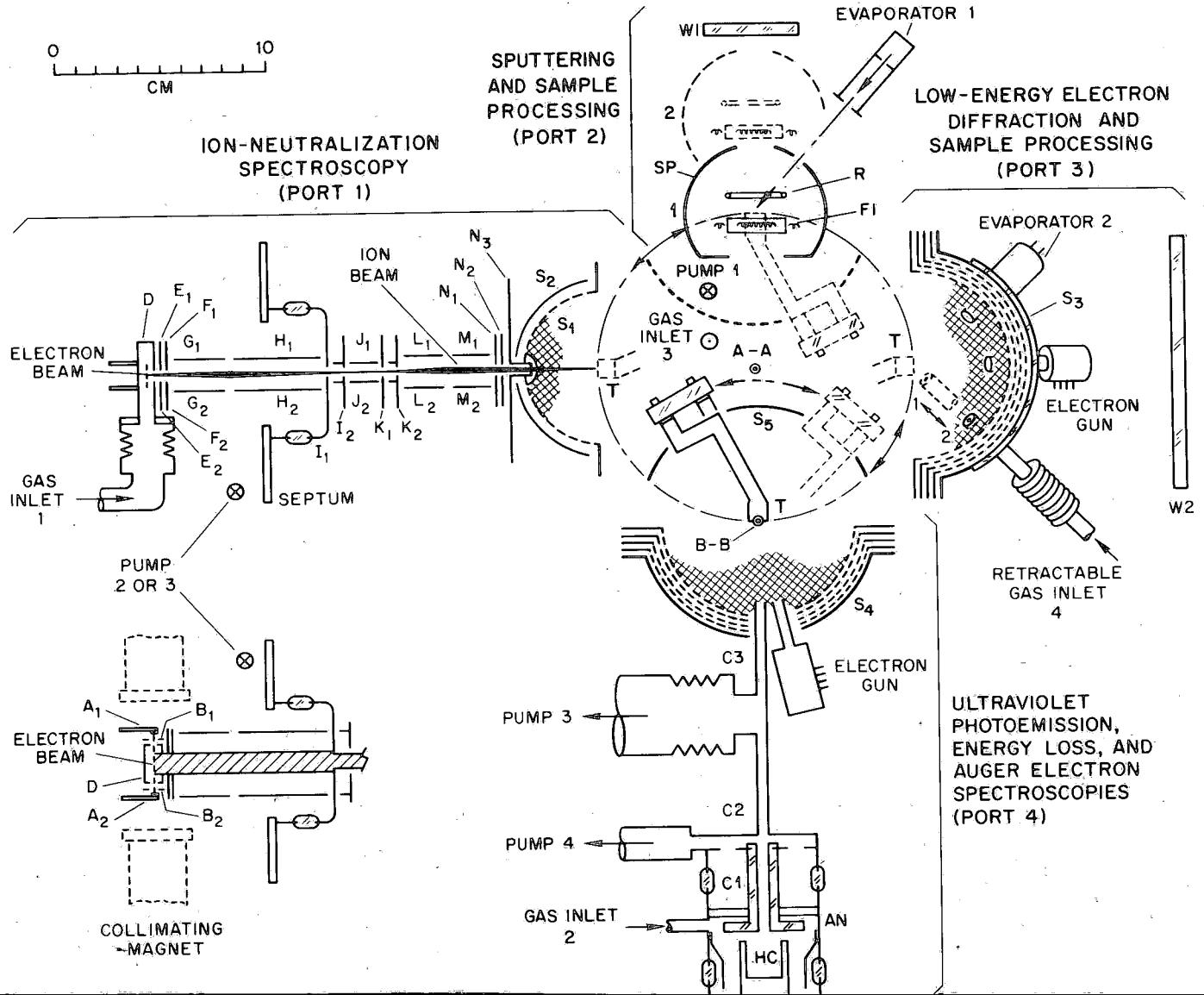

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degradation of every element of an iron, steel, alloy, and even polymeric age. For polymers, too, degrade at the surface first. Thus the wants are abundant.

Technology Supports the Integration of Science

We now return to the theme that the way to meet needs, through the quality and direction of technology, can be largely influenced by intensive research that combines several fields. This tends to assure that the research output, language, and parameters are in technological form, or at least accessible to modern technologists. As we have said, the crucial factor in stimulating and sponsoring such research is intensity in combining disciplines. These are usually ones the traditional academic practices carefully avoid combining (except for our special efforts in 1960-61 to establish a dozen university interdisciplinary materials science and engineering laboratories sponsored by the federal government).

Thus, Hagstrum, although concentrating on the fundamental physics, used materials of the highest chemical and metallurgical perfection. With these he made surfaces and applied the best electronics techniques in observing the interaction of charges between free ions and the atoms and electrons in the surface of the solid itself, as indicated in his comprehensive apparatus as seen in Figure 5.

Accordingly, we have added to the notion that, although every separate thing has a surface, and thus it is generally a good idea to know about surfaces, in fact science can nowadays guide a technology of surfacing. This is in dimensions quite strange to a long and successful history of scientific/engineering surface work in nominally separate fields. These include engineering corrosion protection (inadequately used, as noted), catalysis, film formation, and, more lately, integrated circuitry and epitaxial film growth, so fundamental to such circuitry. A variety of other technologies, such as heat transfer, solar and other radiation engineering, and so on, also depend on surface effects.

The same theme could be found in many other arenas in which basic science at first rarely matches the needs of new technologic projects. However, when the total system is properly perceived for development, numerous intersections of scientific research can be found by alert and informed R&D people. To achieve this requires a substantial amount of common language, which in turn means depth of education and a culture itself, such as in phases of electrical engineering, chemistry, and a few other fields, where the science and the technology have long had common roots.

The importance of communicating both in terms of laboratory-wide information systems and bibliographic resources, but also through good "buzz words" for a given style ("solid state," "dislocations," "monolayer," "junction") cannot be overemphasized. We seek to exploit this language-sharing and attention-getting in every way. We developed a computer-based, permuted indexing of titles on the simple chance that words would be seen during the scanning of long title lists of technical reports and papers. This seems to have

Figure 5. Homer Hagstrum's apparatus uses a combination of sophisticated electronic techniques for surface structure analysis.

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happened, and the display of key words permuted from titles of technical reports is now widely applied.

However the mechanics are worked out, the crucial factor of stimulating and transferring the right breadth of scientific knowledge is the key. This is where sophisticated judgment is demanded, because, as we have seen, the science that is most effective is often the least attractive at the beginning; it is the least recognized by the style-setters in the community of science, in accord with present-day practices in funding of university and other basic science; and it is likely to be the last to receive necessary sponsorship. Further, even when the right scientific themes to support a new technology or to guide an existing one have been recognized, unusual organizing, funding, and evaluating efforts are necessary; for these have to carry the work far enough, particularly deep enough, so that the work can actually succeed amid the time and cost pressures that truly effective and virtually all industrial technologies must sustain.

Personal and Cultural Demands of Integrated Science

Some further qualities of this strategy that have been applied intensively to the issue of linking science with technology should be noted. It has required steady efforts to adapt the strongly rooted traditions of the individual researcher. These efforts are propelled by curiosity, and almost equally by the fashions and tastes of peers. These two factors have been joined with a modified exercise in research—namely, this exercise requires probing more deeply than customary into given fundamentals of the behavior of waves, matter, signals, and subjects. By comparison, in modern scientific and even engineering research in an academic context, it is quite necessary to assure priorities in publication and volume of output (in terms of "publish or perish"). This forces continuous moves in "finishing up" or shifting studies once the general shape of a given new finding is established. Further, in the course of doing this and, increasingly, in the manner of publication favored nowadays, with a proliferation of specialized journals, the language of such immediate reporting is specialized and frequently obscure. The realm of particle physics is a familiar example.

Rather different is a modified strategy of twentieth century research appropriate for stimulation of, and transfusion into, development and technology. This requires strong persuasion and patient and detailed use of role models. These should help the promising new worker, coming directly from a necessarily different tradition in a university, to quickly find a different but acceptable commitment. This commitment is to much more detailed, exhaustive, and even more skeptically received (and tested) studies than have been familiar. This altered emphasis takes some generations in a particular community to achieve. However, the findings do spread both ways—back into the more established culture of rapid coverage for the revealing of new truths and concepts, as well as into the direction of meticulous, sometimes plodding, depth of measurement and data-gathering in forms suitable for eventual technological involvement.

Intensive Research as Strategy for Science/Technology

For instance, the early work of Davisson and Germer about fifty years ago[4] in the discovery of matter waves was one among several early basic efforts,

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including new magnetic effects in alloys and mathematical physics of G.A. Campbell on electromagnetic wave propagation. These studies were the kind that gave a base for developing this particular strategy of intensive research into matters having technological potential—even those with little technology at the outset. It is altogether interesting, from the perspective of the last quarter of the century, that those technologists working in association with Davisson and Germer were deeply interested in what positive ion impact might do to electron emission from the surface of oxide-coated cathodes. There was very little intensive basic research on films or surfaces. Yet these surfaces were the basis of vacuum tubes in the new age of electronics then emerging. And indeed, another much later episode in the same laboratories, the elegant work of Bardeen, Brattain, and Shockley in the discovery of the transistor, depended also on surface effects in its early form. The brilliant work of Langmuir, at the General Electric Company, and of a few others had revealed a range of elegant but complex behavior in films. And while nonreflecting fluoride films had contributed technically to lens behavior, that was about all that happened.

However, in the mid-1950s it became evident that matter of high regularity and purity could be obtained because of the ingenious (and equally detailed and painstaking) application of the phase rule by W. G. Pfann. He produced zone-refined single crystals of silicon, germanium, and other matter. Also, appropriate theory was emerging for understanding the interaction of charges outside of matter, such as of ions approaching surfaces with those on and below surfaces (the Auger effect and many derivatives). We thought the time had come to begin to establish the "environ of intensive research" that it was hoped would reach into some emerging technology.

Efforts of Hagstrum and his associates took shape somewhat more deliberately, but this particular period saw concerted and focused endeavor to create an appropriate condition: to move a particular part of Bell Laboratories' enthusiastic role in the already flourishing pursuit of solid state science and electronics technology into an additional, somewhat different position. Conditions would be sought, leadership oriented, and resources provided to interrelate several scientific disciplines significant for films and surfaces. These included basic mathematics through modern computing aids, onward to theoretical physics, experimental physics, chemistry and metallurgy, and, where necessary, insights from the life sciences. These would all be combined in a community that was already organized to surround the phenomena of waves and matter. Such had by then, in the three decades after the discovery of matter-waves, been identified as the most promising approaches to our technology. This is the technology of signals and their processing—the basis of telecommunications, computers, and information machines.

Evidently such a "surround" would mean that new generations of scientists also needed to be attracted to this enterprise in surfaces and films. All participants were expected to get into the complexity and obscurity that were assured by the engineering mystiques of microwave circuits, radio, crystal detectors, capacitor instabilities, resistor corrosion, and so on. They would accept such missions only if there seemed to be appropriate sociotechnical rewards and congenial peers. To get these is an admitted risk, too. But it seemed that the whole task could best be approached by encouraging *new science*. This had to relate to engineers and technologists who had long been left to adapt what little know-

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ledge there was to the very real and demanding problems they had to solve. Surfaces and films were notorious for generating such problems, as, indeed, had been the impure crystal and the unstable material in the decades before.

Actions Embodying Strategy of Intensive Research

To emphasize the qualities of work that were expected, a Department of Theoretical Physics was established under the leadership of W. Conyers Herring. His earlier willingness to transform his pioneering studies with Professor E. P. Wigner on the band structure of alkali metals into new kinds of work, such as a detailed examination of the surface changes involved in sintering in powder metallurgy, was evidence of the spirit that was required. Theoretical work, properly conceived, is a most powerful way of intensifying and integrating physical science.

We must emphasize again that this strategy of the intensive multiskill approach to broad technologically shaped natural science, such as the signaling qualities of waves and matter, is by no means just turning a lot of scientific talent and energies on a course vaguely pointed toward technological goals. Rather, it is the method we have used to define and, we hope, to create new technologies. They, in turn, thus become the cause of innovation for human and national benefit. Indeed, there is a variety of experimental evidence supporting this alternate route to guidance of technical innovation. This comes not from technological assessment or specification of what is permissible but, rather, from gradual and progressive scientific modulation of technological systems and services.

In this way it appears that society can expect to have the best, or at least a sampling of the best, technical capabilities of its time. These may be involved in any particular innovative area, whether food, shelter, clothing, health, transport, communications, or any other fundamental need. This is a notion somewhat oblique to, but very close to, the concern of how best to deal with technical change. For it is a statement of a creed that if we can rally the best minds to surround the best opportunities, civilization will advance. Thus this synthesis of an intensive research community (that, for example, studies surfaces with a detail that neighboring technologists enjoy and understand) is a way to approach the many compelling needs for the future. Yet, in energy systems, for example, from automobile propulsion to megalopolis generating stations, there are common themes that no national laboratory or industrial center is yet exposing to this notion.

But the implementation of these ideas takes time and tender care. Nearly half a century past the time that Davisson and Germer puzzled over the surface qualities of nickel crystals as revealed in the scattering of an electron beam, J. M. Poate at Bell Laboratories and his co-workers from other industries and the university reported and edited achievements of intensive research in surfaces and films.[5] There it is seen how basic science of surfaces and films has been turned into a comprehensive technology, in which processes of surface and film formation can be applied in many engineering systems.

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The Case of Films for Microelectronics

Examples of these themes of initiating and guiding technology in concert with very detailed scientific study (arranged to assure multidisciplinary content and language so that the engineer quickly encounters familiar formulations in basic research terms) occur in various new programs. These are indeed having, and will continue to have, strong influences on the shaping of modern society and of economic affairs. One of these is an evolution from the transistor and solid state electronics findings of the mid-century, whose basic research origins have been noted. Its emergence now appears in the present period of thin film microelectronics and integrated circuitry. Another is the oncoming era of photonics, which may eventually compare with electronics in the scope and value of the use of lightwaves or photons for communication and information handling, as electrons and other electromagnetic waves have been used earlier.

Crucial decisions on how to create a technology suitable for commercial application in these fields come largely from basic knowledge of physical and chemical qualities of the system. This must be coupled with scientific and engineering knowledge of what the components can be expected to do in eventual subsystems and systemic use. In the case of integrated circuitry, again surface science is pervasive. The theme is to apply the knowledge of bulk properties of crystals, derived from the transistor and other semiconductor era, to virtually two-dimensional arrays. These of course can be governed by crystal structure of the substrate on which thin films are deposited (crystal epitaxy). In other words, new surfaces preserving nevertheless a bulk atom packing can be condensed from vapors or molecular beams. The challenges of that delicate process are well displayed in the studies of K. A. Jackson and his co-workers by computer and other theoretic simulation of the way atoms condense from vapors and liquids to

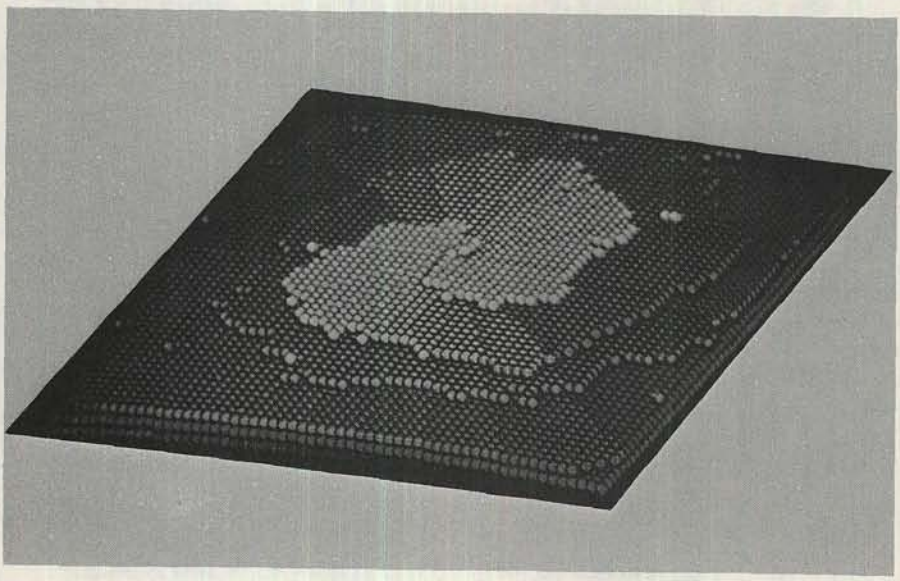

Figure 6. Computer model of spiral growth process in crystals. The vertical screw dislocation (in the center of this model) acts as an active growth site, perpetuating its spiral structure.

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form solids. As shown in Figure 6, this process often occurs with the formation of a spiral layering of atoms that will leave imperfections and whose amounts have to be carefully contained. Indeed, as shown in Figure 7, even non-crystalline films deposited from vapors may have minute cracks or other discontinuities, as revealed by careful electron microscopy. Stereo pairs from such electron microscopic observation can show in a very thin layer what is nevertheless a three-dimensional distribution of inhomogeneities.

It is found, however, that these details of film and surface formation can be controlled. Thus extensive effort was devoted to building in the right composition, so that the electronics desired from individual atoms and their bonding could be created. The implanting of these special atoms by means of acceleration of their ions in a particle accelerator, such as discovered by Sir John Cockcroft and Professor Walton for the study of nuclear structure, was undertaken. This effort was highly successful in operating, as shown in Figure 8, to

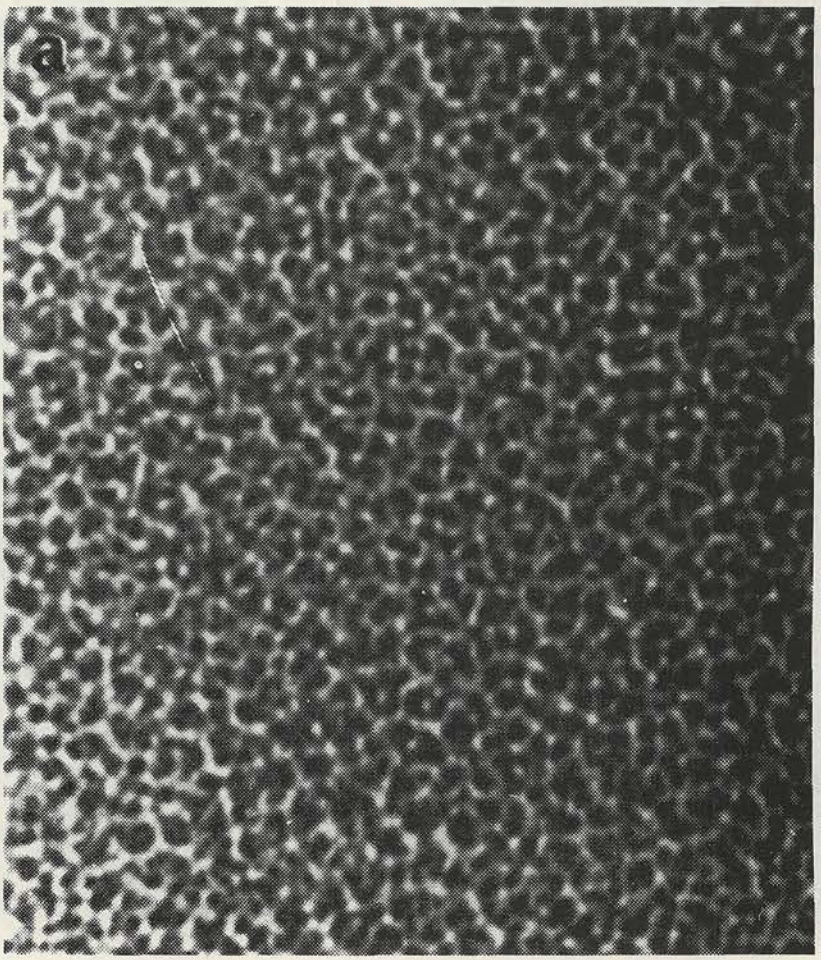

Figure 7. TEM micrograph showing the presence of a crack network in an amorphous sputtered GE film ($\Delta f = -5.2\mu$m).

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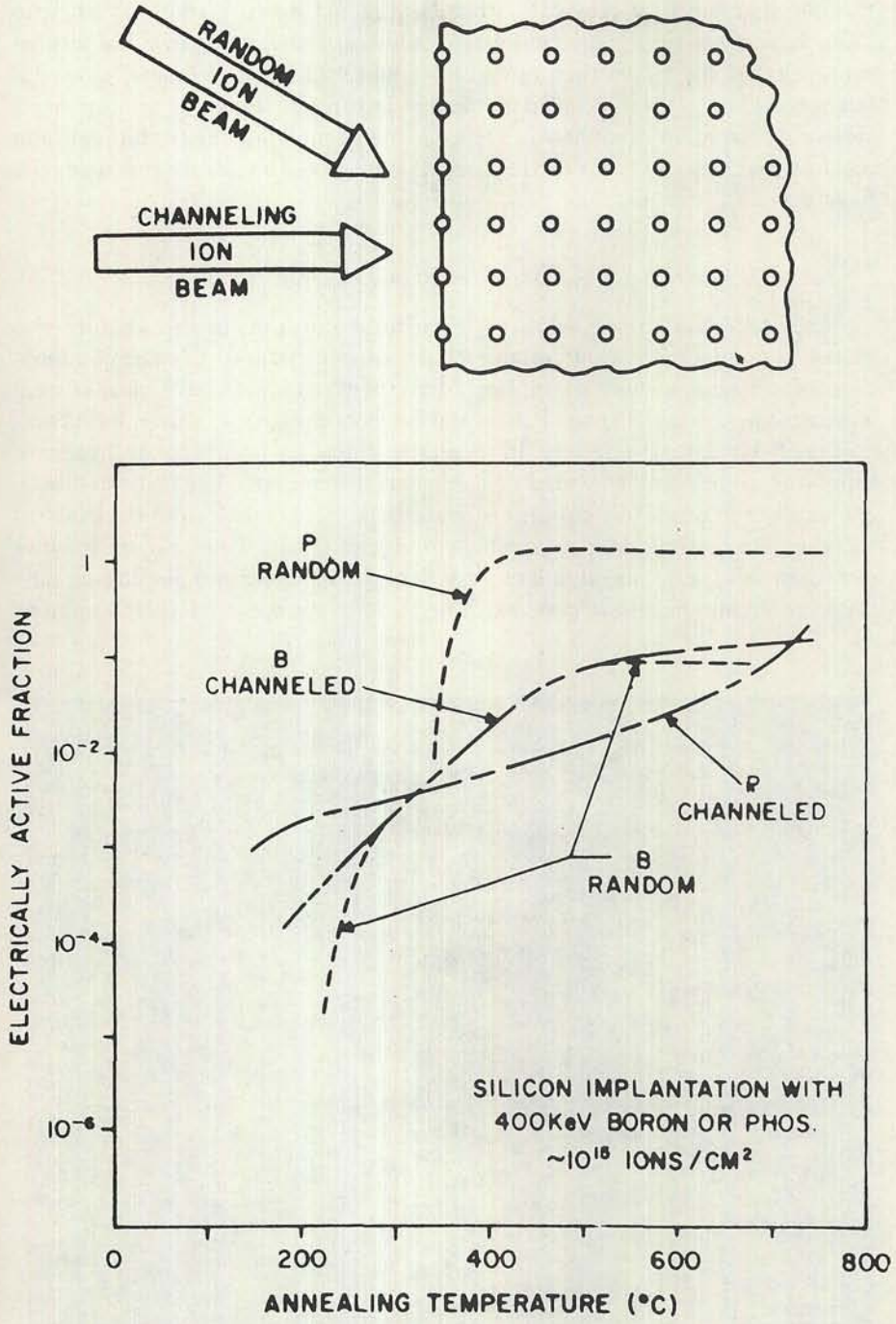

Figure 8. By the implantation of selected atoms in thin films, electronic devices suitable for various circuit functions can be made commercially. Ions are injected by beam and then stabilized by heat.

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inject the necessary atoms into layers of the thin film. As indicated in the figure, the injecting beam of ions can either be directed down certain crystal axes ("channeling") or simply used anywhere on the surface ("random"). The electrical results, as the film is then heated to stabilize the injected atoms, show differences. These reflect detailed structural features revealed by the intensive surface research discussed above. Hence, suitable junction devices for logic and memory and other circuit functions are now made commercially this way on a huge scale.

Intensive Research and Advanced Integrated Electronics

The successful atomic synthesis of surfaces and films in this venture also sustained our decisions to attempt much more extensive and elaborate combinations of surface and film assemblies. Many new structures have been created already. The work of Morton Panish and his associates, for instance, has generated the heterojunction devices. In these, the atomic environments of successive thin films, comprising a layered or laminated system, have been adjusted both chemically and physically to optimize the charge carriers (holes and electrons) in mobility and lifetime. Unprecedented efficiencies result. Thus, Figure 9 shows a modern solid state injection laser, essential for signaling and amplifying new photonic communications systems. The various surfaces and their junctions

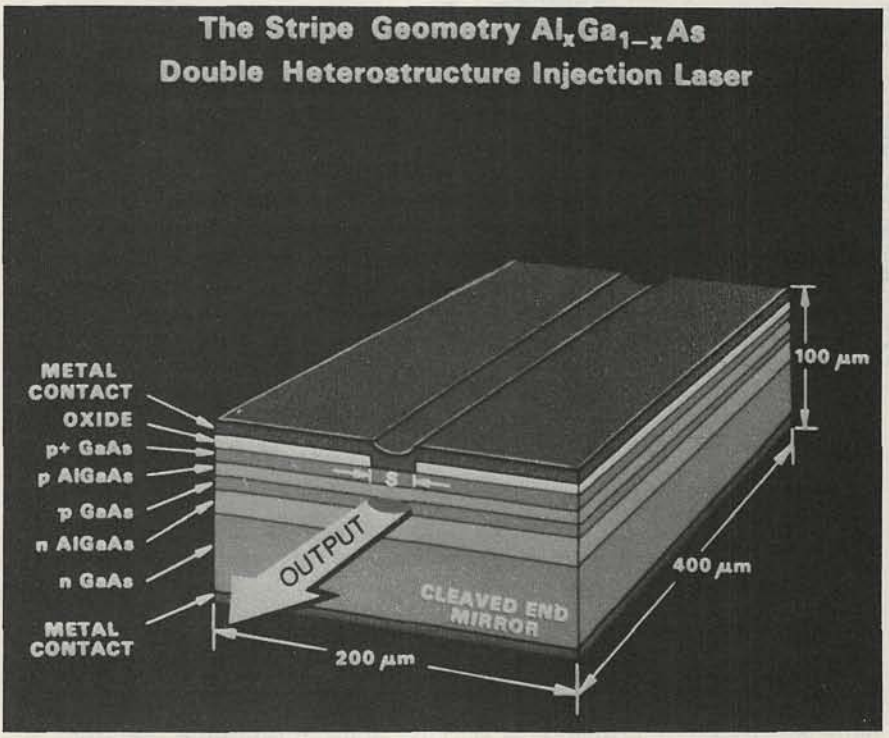

Figure 9. Modern solid state injection laser with stripe geometry.

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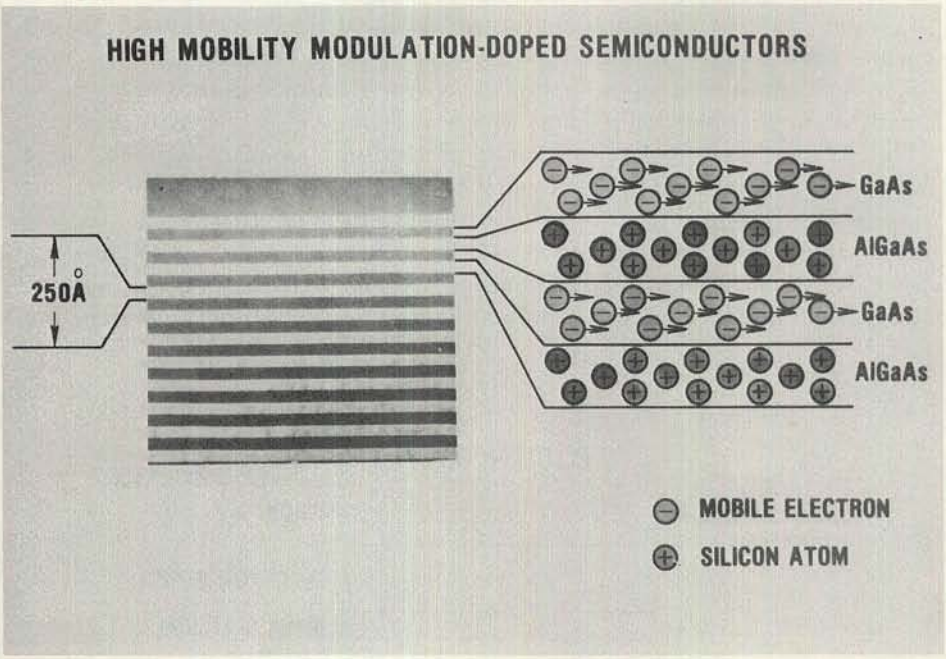

Figure 10. High-mobility modulation-doped semiconductors consist of thin-film layers deposited by molecular beam.

permit the proper charge production and recombination. Figure 10 shows a new layered semiconductor, in which, literally, the atomic environment is synthesized by formation of thin films from a molecular beam. Here, the mobility of the essential charge carriers has been enhanced to approach an ideal level. This was envisioned theoretically when the transistor itself was discovered, but its practical realization has awaited the detailed science of films and surfaces, whose technological impact illustrates our principle.

Science Accessory to Thin Film Circuitry

Another feature of the technology of integrated microelectronics and their reformation of communications, computers, graphics, sensing devices, and controls of engines and other energy converters is the patterns of the circuits themselves. These are literally the circuit designs that make the subsystem. We have spoken of ways that the films and their surfaces are formed and of the role of deep scientific study in defining and controlling that process. However, perhaps even less obvious is the scale of scientific guidance that has helped to shape the technology of film-making, which is necessary in achieving the patterns, or the outlines, of circuit elements. These actually work as transistors, diodes, resistors, inductors, and so on through which these films are turned into working circuits. First, sophisticated basic studies were necessary in order to reach the dimensions of a few thousandths of a millimeter. These are now goals for the

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line widths defining these circuit elements in a given film. For instance, Figure 11 depicts a modern way of using this technology derived from a master layout of the circuits (itself produced by a computer-aided process). This machine drawing is transferred by the motion of an electron beam to form a microscopic mask, through which the various thin film deposition processes then occur. This mask is thus crucial in assuring the sharpness of boundary between, say, a conductor and insulator in the eventual circuit, a matter of high importance for precise electrical quality. It turns out that the goal of creating such a mask or, essentially, a resist from an electron beam exposure is a matter of polymer science—the knowledge of very large molecules. For the electron beam can convert chemically an appropriate polymer film into a more soluble system if a

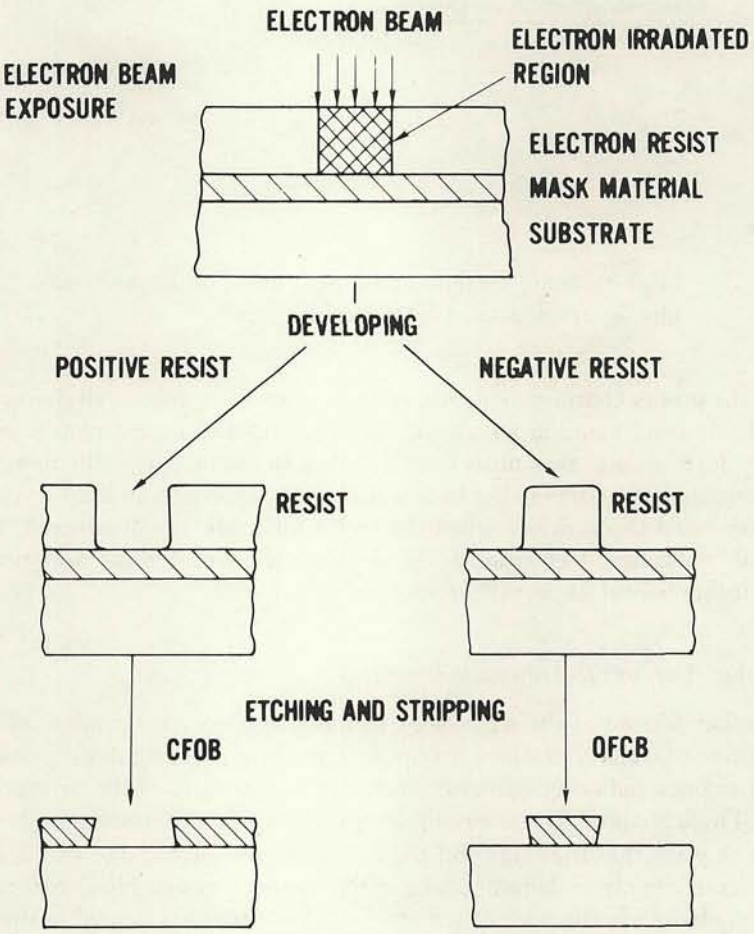

Figure 11. Integrated circuits can now be both designed and manufactured by computers. Electron beams form the various elements of the circuit according to master layouts.

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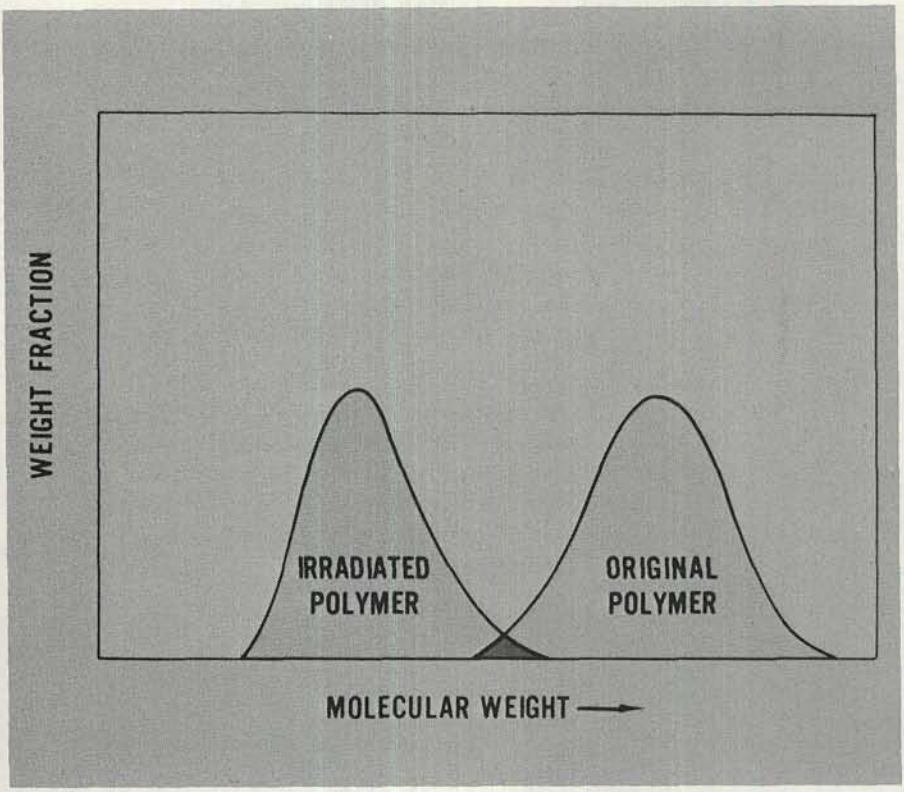

Figure 12. Chemistry of a polysulfone for thin-film circuitry. The marked difference of molecular weights of the polymer before and after irradiation is highly desirable.

degradation by electrons is chosen, or, conversely, into a less soluble one if a cross-linking by electrons or X rays is chosen. In the former case, the subtle matter of the distribution of sizes of the giant molecules forming the polymer film is crucial. Suppose the polymer film is made of a polysulfone, whose chemistry is represented in Figure 12. In order to have the very sharp definition in the "developed" film after the electron beam has converted the polymer it strikes into a lower molecular weight (smaller molecular size form), it is at least necessary that there be a relatively sharp separation of the molecular weight distributions. This means that most probable sizes of the original unirradiated molecules should be distinctively larger than those that are irradiated. As Figure 12 illustrates, this is accomplished by the particular kinds of polymers chosen. However, many years of polymer science and research were required to understand the meanings and methods of control of such distributions of molecular sizes.

Once again, the combination of disciplines, each of which has a fairly strong academic separation from others, is essential to this technological advance. Figure 13 shows one of the results, a microprocessor of unsurpassed elegance and compactness. Its equivalent (rear) is already remarkable technology on a scale of

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the most useful present-day computers. But the little chip, being held, appropriately enough, digitally, is far ahead of what we have had before. We believe that it is the forerunner of new capabilities and efficiencies in communications, automata, and, indeed, control of virtually all kinds of modern machines. Automobiles, household appliances, factory lines, and many other systems will use energy and perform their functions under elegant control of these chips.

Oncoming Cases of Science/Technology Junctions

Such ways of shaping technology through intensive research are appearing in various other subjects. We mentioned before the coming age of photonics. Here, the frontiers of optics opened by the laser invention and research have extended to one of the oldest and most valuable technologies. This is the use of matter transparent to visible light, generally based on silicates, and called glass. In comparatively recent times glass has been made in the form of fibers, following the invention of Games Slater. These have been of high mechanical, thermal, and optical value. Their optical use has concentrated especially on viewing remotely such important elements as the interior of the human body. Good

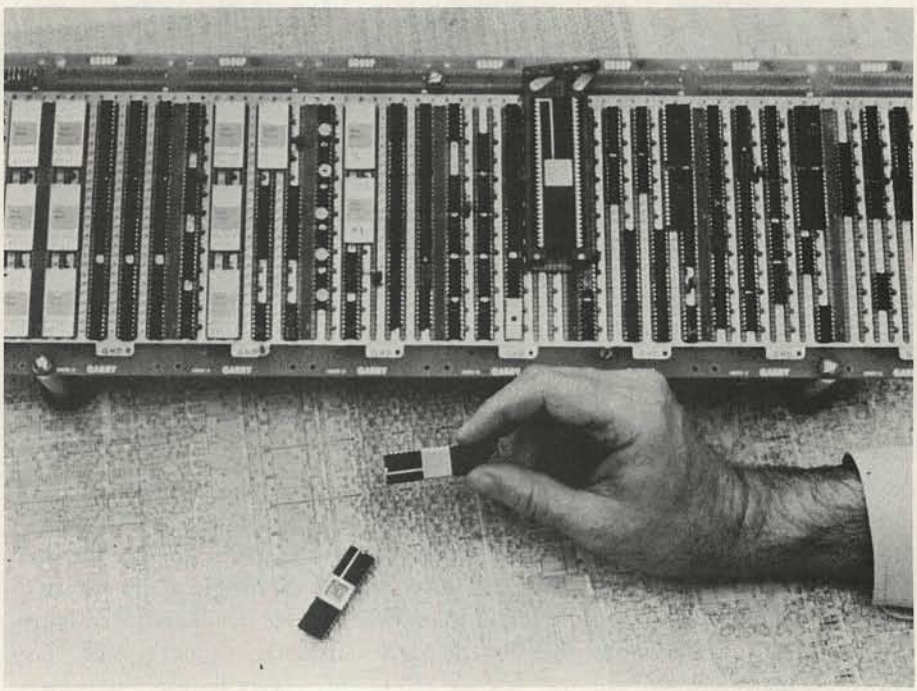

Figure 13. Two MAC-8 microprocessors (foreground) compared to one of the two circuit boards that are the equivalent of one of these new chips. The MAC-8 microprocessor is able to execute over 100,000 logic functions per second, while using only one-tenth of a watt of power.

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quality glass, such as for lenses, made into such fibers has given adequate clarity for the light transmission that was required. However, with lasers, photon input can be so strong and so controlled (being coherent light of single wavelength) that very long distance transmission could occur if glass were clear enough.

In Figure 14 we see an experimental example of a new realm of technology, in which the solid state laser is attached to a tiny glass fiber the diameter of a hair or less. Now the point is that the qualities of this glass have been changed, through the methods of intensive and combined research, to support the new lightguide technology. The change is an exciting reminder of what is possible in modern research and development. We note that from early times, such as Egyptian culture (and glass is one of the first materials to be processed in civilization), there has been a steady move toward clarity, shown in Figure 15 as

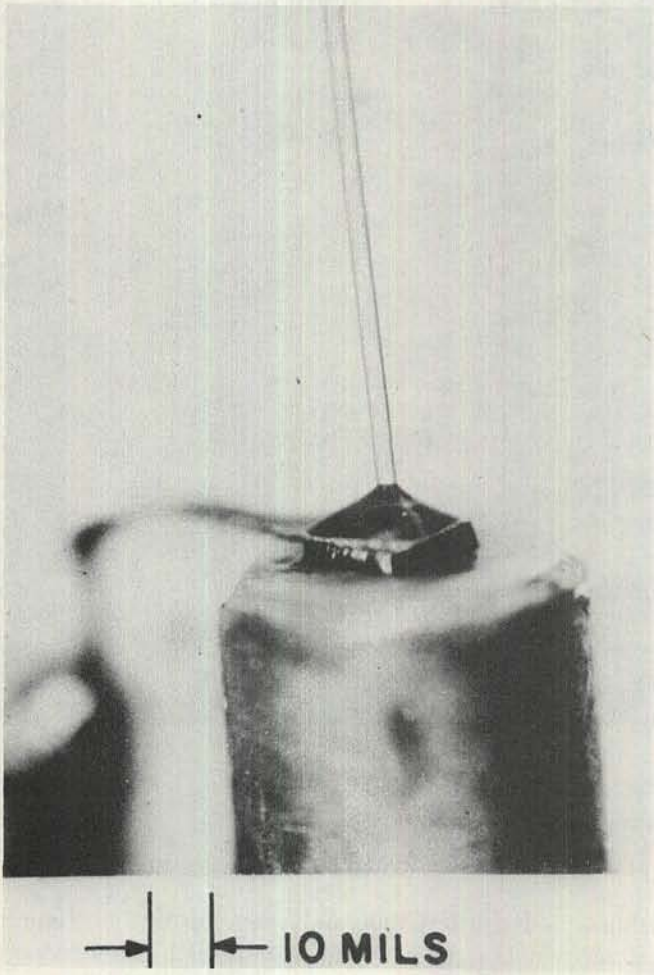

Figure 14. Extremely fine optical fiber attached directly to a solid state laser (much magnified).

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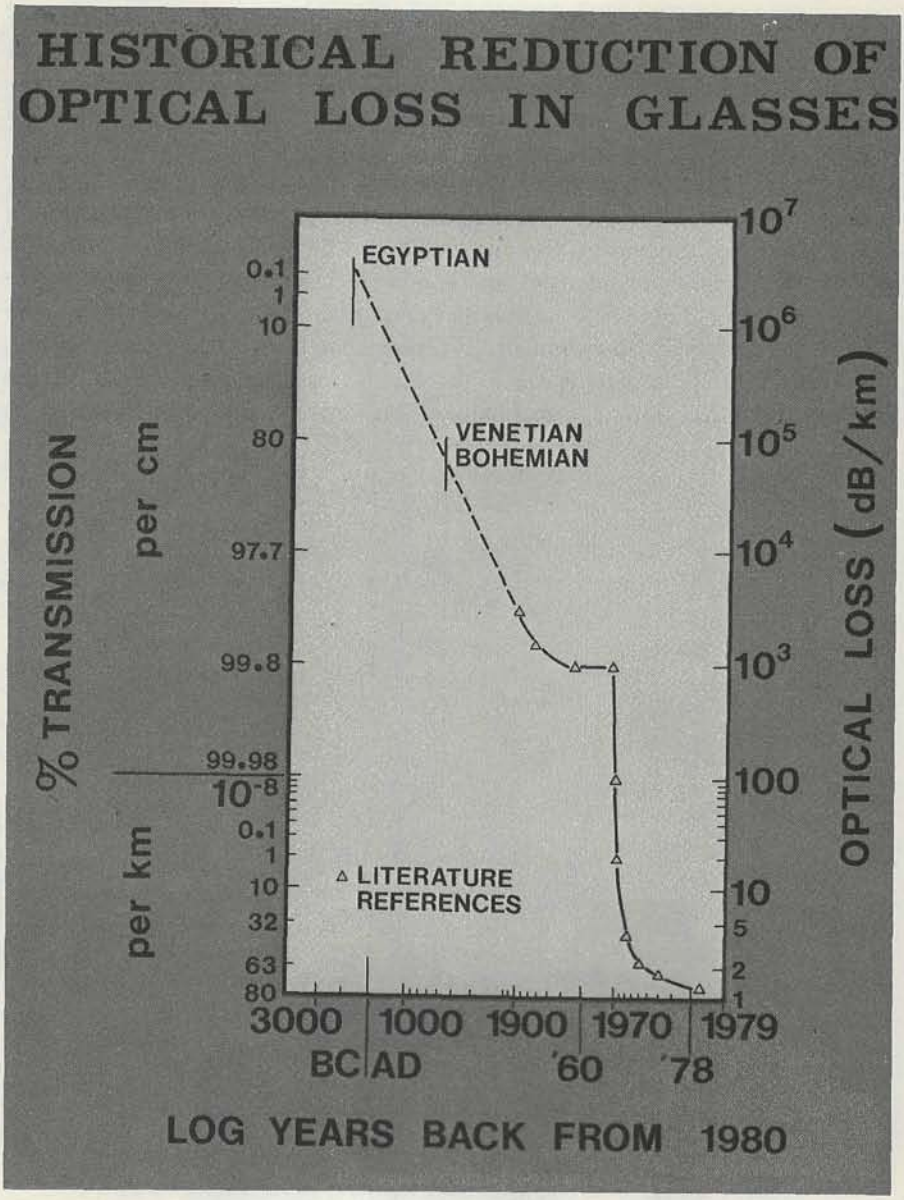

Figure 15. Reduction of optical loss and increase of clarity in glass from ancient Egypt to the present.

percent transmission. For a few thousand years, up to the beginning of this decade, that improvement in percent had gone through many orders of magnitude, to about 99.98 perfect clarity. We see that about 1970 the plot has leveled off, and the great glass makers indeed felt that a limit had been reached for this mainstay of civilized materials. However, with the stimulus of research connected with laser technology and the recognition that photons could be major

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resources of communications and information processing, beyond even their great use in photography and other imaging (digital photon pulses are the prime new element), another period of glass properties has emerged. Here, in terms of the optical loss in decibels per kilometer, three orders of magnitude improvement have been achieved in this decade. In fact, the fibers we are now using in a variety of lightguide communication and data processing systems have this thousandfold improvement in clarity, in the neighborhood of 2 decibels per kilometer or less loss.

This astonishing progress is but another example of how the particular ways of intensifying research toward development can be worked out. The significance for systems qualities can be suggested in Figure 2, where the sort of analysis that we believe is necessary for the best guidance of technology, and thus, indirectly, the appropriate opportunities for research, is represented. Namely, we see the evolution of transmission media for telecommunications as it may evolve in two centuries. For telephone usage, we note the bits per second of various telegraph efforts, which in turn succeeded smoke signals, and so on. The logarithmic advance in capacity during the electronics era is prominent. It is an end-product of particular kinds of electronics that we have discussed above. But, then, in a higher scale, far above the curve of the last century and a half, appear the potentials for the lightguides. These potentials seem virtually certain to be realized. So the effort that was risked in this field two decades ago as intensive research appears to have been justified.

Thus, we can conclude that the fields of communications and information processing, which according to Porat's studies now comprise somewhat more than half of the nation's total Gross National Product (primarily the information service industries in comparison to manufacturing and agriculture of the earlier period), have responded to interactions of science and technology that we have outlined. Indeed, the time covered, about four decades of this century beginning in 1940, has corresponded to the major growth of that economy. Thus it seems that our estimates of how these strategies of discovery and application of new knowledge have worked are warranted.

Thus, in Figure 16 we report that the major elements of the communications industry are represented by integrated technology now based extensively on the science sampled in this discussion. We see that it is possible to characterize and to seek to optimize the interrelations of all these elements, which provide services to human beings through elements of electromagnetic signals. We have not dug into one of the most vital aspects of this, which is the distribution of capabilities through switching, where many important mathematical and scientific principles have also been generated and used. However, the essence of electrical computers, particularly as illustrated in our comments on the microprocessor, is at the heart of modern switching capabilities.

Overall, we believe that society's options to employ technology can basically include ways to involve the ablest minds. This crucial factor occurs through appropriate research environment and science methodology, which relates strongly to similar modern cultural features of the individuals who undertake technology and engineering. Common learning and languages, and facilities, especially through digital computers, are making the connections within these communities stronger than ever before.

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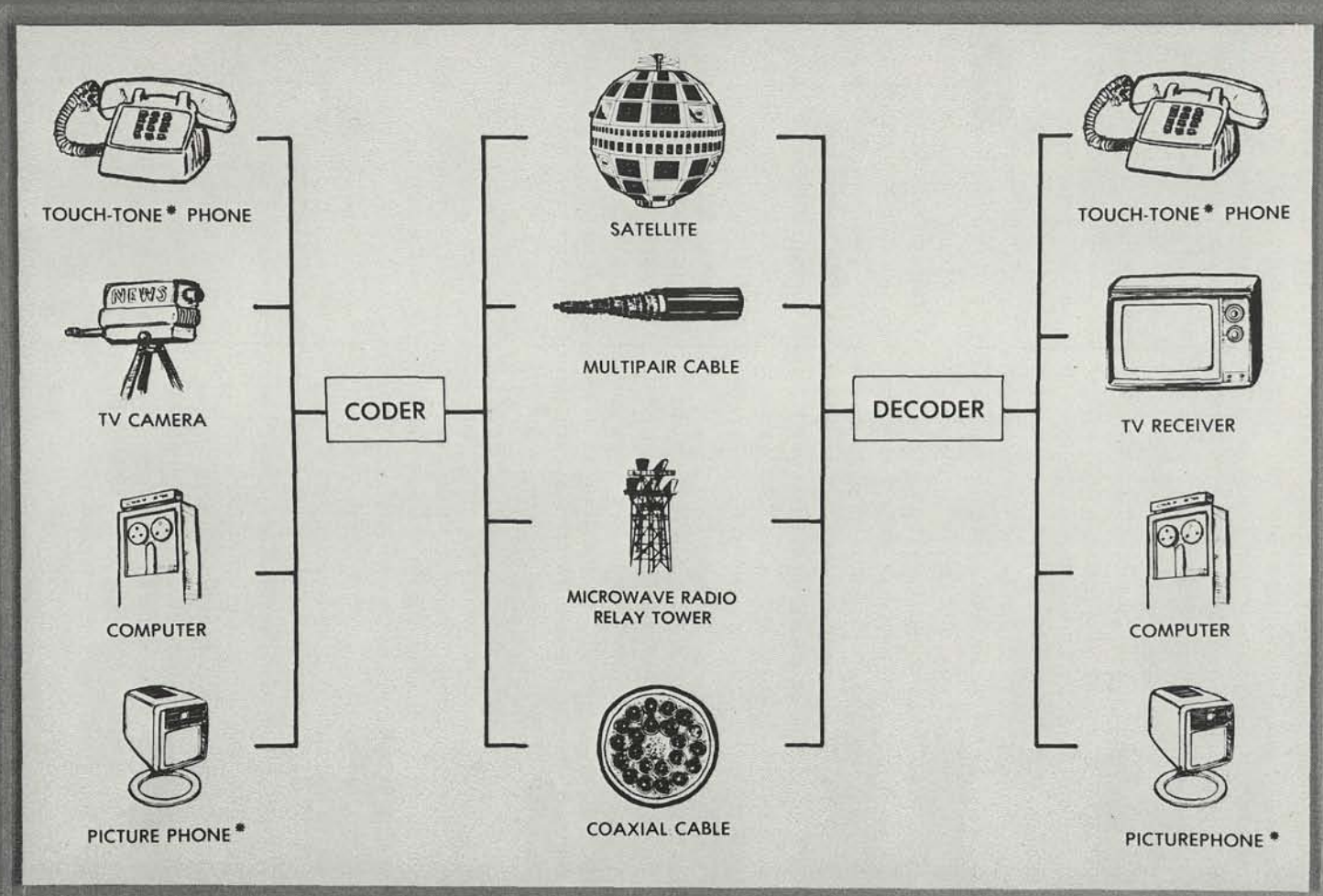
TRANSMISSION MEDIA



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It is to be hoped that other major social needs, such as health, energy conversion, transportation, and so on, will be approached through systems science, employing the tactics that have been touched on. This will, of course, require large and closely interrelated communities for research and development. Above all, it would also require a style of leadership quite different from conventional product management and marketing. For instance, society will be required to decide whether ancient and arbitrary restrictions on size of industry and other institutions (causing fragmentation of innovative effort) are to be preferred to competency in world competition. Are such restrictions better than a range of choices based on knowledge rather than policy?

REFERENCES

[1]W. O. Baker, "Problems of Innovation and Change," *Proceedings of the Twenty-Third National Conference on the Administration of Research* (1969): 89-98; "Man and Machines," *Random House Encyclopedia*, New York, 1977, pp. 1578-1581.

[2]E. Wenk et al., Committee on Commerce, Science, and Transportation, U.S. Senate, Oversight Hearings on the Office of Science and Technology Policy, Subcommittee on Science, Technology, and Space, March, 1979, Serial No. 96-11.

[3]J. W. Forrester et al., *Principles of Systems* (Cambridge, Mass.: Wright-Allen Press, 1968); *World Dynamics* (Cambridge, Mass.: 1971).

[4]R. K. Gehrenbeck, *Physics Today*, 31 (January 1978): 34.

[5]J. M. Poate, K. N. Tu, J. W. Mayer, *Thin Films—Interdiffusion and Reactions* (New York: Interscience, 1978).

Figure 16. A diversified telecommunications system transmits signals by means of various media—under, on, and above the ground.

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DAVID LANDES

The Creation of Knowledge and Technique: Today's Task and Yesterday's Experience

THE HEART OF THE WHOLE PROCESS of industrialization and economic development is intellectual: it consists in the acquisition and application of a corpus of knowledge concerning technique, that is, ways of doing things. It is customary for economists to think of this corpus of knowledge as a common property of mankind, a pool into which any and all can dip at will. This assumption of general accessibility is subject, to be sure, to a significant constraint: the existence of secrets, which may or may not be protected by patent. The existence of such secrets is inherent in the character of knowledge, for knowledge is not given, it is created, and there is always a lag between the creation of knowledge or the exclusive application thereof by the creator and its communication or diffusion to others. Such secrets, however, are assumed by economists to be short-lived. Given the fact that the scientific knowledge from which technology is commonly derived is almost always published and widely disseminated, any attempt to keep a superior technique secret is bound to fail. If the technique yields a product, the object itself will almost invariably yield up its secrets to the expert eye. If the technique concerns a way of making the product (if it is what the economist calls a process innovation), imitators will either learn it (sometimes by illicit means) or find an equivalent or better substitute (there is more than one way to skin a cat).

All of these theses concerning the nature and accessibility of knowledge are based on the experience of what the economist calls advanced economies. These are those few industrial nations that not only possess technologies on the frontier of human knowledge and performance, but are capable of training new scientists and technicians to work in the context of that technology and push back that frontier. Short of that happy state, however, the great majority of the people in this world are barred from access to much of this knowledge and seriously hampered in the application of such knowledge as they have. They are barred by their lack of appropriate education and training, the inadequacy of their resources, and their inability to mobilize and organize such resources as they have. Small wonder that a demand for technological parity constitutes a key plank of the platform of the so-called New Economic Order.

The advanced nations have not been unmindful of the handicap imposed on less developed countries by their ignorance of, and inability to apply, more efficient techniques. Insofar as those who possess this knowledge and enjoy the

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fruits thereof feel a moral obligation to reduce the gap between rich and poor, or perhaps have a prudential interest in doing so, they have been especially sympathetic to projects for the dissemination of technology. For one thing, if I may be permitted a materialist observation, knowledge is the one commodity that can be given away without impoverishing the giver. For another, it is far cheaper to teach people how to do or make things than to give them the things or, even more expensive, give them the means to make things without really showing them how.

These projects for the dissemination of knowledge have thus far had only moderate success. To the extent that advanced nations have received students from less developed countries and offered schooling and training, they have often succeeded only in adding to their own pool of scientists and technicians. American hospitals are filled with foreign interns who find the practice of medicine more remunerative and satisfying in this country than in their own poor countries. This and other examples of "brain drain" have been the subject of much moralizing and hand-wringing; but it is hard for free societies to exclude those who have in a matter of years set down roots and have acquired skills and talents that are of value not only to society at large, but to hospital administrators and laboratory directors trying to balance their budgets.

Those who return home, moreover, are as much unprepared by their experience as prepared. They know much more than when they left, but often it is the wrong knowledge—agricultural techniques, for example, that make sense in temperate climates but not in tropical. Even when they know what they need, they may lack the opportunity to apply their knowledge: equipment may be inadequate; collaborators, few and deficient; complementary services (especially governmental), wanting or maddeningly incompetent. Sometimes it may be easier to know less and try less than to know more and not be able to try or do.

As for those trained in the poor countries, they may be less surprised by the impediments to postgraduate application and achievement, but they are no less frustrated. For all the limitations of their training, they have been sorted out by it and raised beyond the knowledge, comprehension, and even sympathy of their compatriots. They, often along with those trained abroad, constitute a small elite in a sea of conservative custom, fearful self-interest, and ideological suspicion. The private sector is weak; the public, ineffective, if not corrupt and malign.

Finally, there are the foreign experts, many of them idealistic volunteers ready to accept unaccustomed hardships and difficulties in order to do something for those less fortunate. Their efforts are often rewarded by small and big successes, by the introduction of new and better crops, by a reduction in infant mortality, and by the adoption of more productive techniques. At their best, though, they are not the remedy for technological backwardness. History shows that foreign craftsmen and technicians can do wonders in teaching new ways to a less skilled population. Indeed, there is hardly an advanced country that has not benefited enormously from the migration of knowledge—the English, from the Flemish weavers of the so-called new draperies (16th century); the French, Belgians, and Germans, from British mechanics during their industrial revolution (19th century); the Americans, from a steady stream of skilled (as

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well as unskilled) settlers; the Japanese, from European technicians hired on during their drive to modernize under Meiji (post-1868).

The same record, however, tells us something of the conditions of effective absorption of foreign knowledge and techniques. Most of these countries kept their visitors, who constituted a permanent addition to the stock of human capital; and to the extent they did not or did not want to keep them (Japan is the best example here), made it a point to get from them whatever they had to teach before sending them on their way.

Now, this is surely the kind of task that confronts the less developed countries of our day. They will not hold their visitors, nor is it clear that they want to; and this means that they must learn these techniques and—much harder—learn to generate new techniques themselves. Outsiders may help, but unless the seeds of knowledge and invention take root, there will be a one-time increase in yield and then a return to the *status quo ante*.

This brings me to the key question: What does it take to learn and domesticate new knowledge and ways, to the point not only of doing things differently and better, but of finding new ways of one's own?

I shall not pretend to be able to answer that. (If I could, I would not be writing this article; I'd be changing the world.) But I think that history can give us clues as to what is *not* the answer. In particular, I think it shows conclusively that knowledge and skills are not disembodied things that can be propagated and received at will, like radio waves or light. Let me tell a story on that point.

In the sixteenth century European sailors began for the first time to undertake oceanic voyages on a continuing, regular basis.[1] They did so in spite of the fact that, once on the high seas, they could know their location only approximately, and that mistakes on this score could cost them their lives. Of the two coordinates that defined their position, they could calculate only the latitude with any precision. Longitude had to be more or less guessed at by a procedure known as dead reckoning: the officers would keep track of the ship's course and speed, and work out its presumed location at the end of each day's sailing. Since estimates of speed were made only every two hours or so, and then with gross margins of error (a floating object was thrown overboard, and the time it took to pass from one observation point to another was measured by the recital of some standard bit of prayer or verse),[2] dead reckoning could be seriously misleading. Sailors making for small targets in wide seas learned to play safe by aiming for points well to the east or west of their mark and then running the latitude to their destination. Even that was not enough, and the annals of sailing are dotted with tales of ships lost because their crews were lost.

For maritime powers of Europe, this was a costly weakness. Ocean-sailing ships were immensely valuable, in themselves, for the crew that manned them, for the cargoes they carried. Small wonder that Philip of Spain offered in 1598 a fabulous fortune to the person who would discover a way of determining longitude: a prize of 6,000 gold ducats, a life pension of 2,000, and a further gratuity of 1,000—the equivalent of millions of today's dollars. No one won the prize, though the scientific principle on which such a method might be based was well known. The rotating earth, after all, is a clock, so that differences in longitude

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translate into differences in time and vice versa—as Gemma Frisius had pointed out a half-century before. Since the time where one was could be determined by astronomic observation—the sun's passage of the meridian, for example—one needed only to have a clock precise enough to keep the time at another place of known longitude, and to convert the difference in time into a difference of distance.

There was no one in Spain, however, or anywhere else at the time, capable of building such a clock. The Spanish government paid smaller, but substantial, sums to numerous postulants who pretended to be well on the way to a solution, some of them cranks promising the navigational equivalent of the philosopher's stone. In the end Spain gave up: necessity may be the mother of invention, especially if backed by money, but there is no substitute for the kind of environment that generates novelty.

Over the next century and more these encouragements and enticements were imitated by the governments of Venice and Holland, in vain, and finally by those of England (Act 12 Queen Anne, 8 July 1714) and France (1716). The English prize was particularly generous: £20,000 (say $6 million today) for a method accurate to within half a degree of arc, or 30 nautical miles. By this time horology had made revolutionary advances. The invention of the pendulum clock (Huygens, 1660) had made possible time measurement to the fraction of a second, thereby enhancing enormously the effectiveness of astronomical observation. But because of the rolling motion of ships, pendulum clocks proved unusable for the determination of longitude at sea. A comparable advance in the production of smaller timepieces, the use of a coiled spring to govern the to-and-fro motion of the balance, whose beat is the heart of the timekeeping mechanism (Huygens, *c.* 1675), held out more promise as a controller or governor. But major sources of variation, hence imprecision, remained, so that some of the leading scientists of the time gave up hope of a horological solution. None less than Isaac Newton, commenting in 1721 on a proposal to solve the problem by "watch works of new construction," noted discouragingly: "It is not to be found at sea by any method by which it is not to be found at land. And it is not yet found at land by Watchwork."[3]

The great pundits may have been skeptical, but some clockmakers and watchmakers were not. The challenge was accepted by a number of these in England and France, at least one of whom, Henry Sully, gave all else up to devote the rest of his life to the invention of an effective "sea clock." In the end, though, it was not a professional clockmaker who won the prize. Rather, it was an autodidact, a carpenter-son of a carpenter, John Harrison of Barrow, a tiny, isolated hamlet in north Lincolnshire, near the mouth of the Humber. Harrison, who was certainly a genius, taught himself to make clocks, using wood for plates and wheelwork, instead of the usual brass. He also so impressed one of the traveling clergymen who ministered at the local church on Sundays, that he lent him a manuscript copy of lectures on natural philosophy by Nicholas Saunderson, Lucasian Professor of Mathematics at Cambridge; and it is clear, from the careful copy Harrison made of text and diagrams, that he learned much from and was much guided by these in his further work in chronometry.

To make a long story short, Harrison succeeded over a period of some thirty years in building a timepiece accurate enough to satisfy the conditions of the prize (completed 1759, tested 1761).[4] To do this, he had to solve a large number

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of difficult technical problems, which he did in the most ingenious but also the most idiosyncratic manner. His first three models were Rube Goldbergian in their size and complexity, far too cumbersome ever to serve at sea; but anyone who sees them working in the National Maritime Museum in Greenwich cannot but be awed by their craftsmanship and artistry. And then he brought out his No. 4, the clock with which he won the prize, a triumph of miniaturization, only five inches in diameter, with an entirely new array of solutions to these same problems.

Interestingly enough, these solutions never took with other makers. Harrison's devices were too difficult or costly to build, even when understood.[5] But his contribution lay in showing that a marine chronometer was possible, that the job could be done. The most gifted horologists of both England and the Continent made it a point to examine his mechanisms and were inspired by them to undertake their own researches and experiments. They found other answers, which proved definitive; but the honor for the great breakthrough belongs to Harrison, the self-taught nonprofessional.

One last aspect of this story deserves notice. The principle of the escapement device that is at the heart of all mechanical marine chronometers was discovered by a Frenchman, Pierre Le Roy; but its improvement and application on a production basis was largely the work of Englishmen, in particular John Arnold and Thomas Earnshaw.[6] And although the French learned to make some of the finest chronometers to be found anywhere, it was the British who came to manufacture the great majority of these instruments. They had the largest market—the biggest navy, the biggest merchant marine. Invention may follow genius, but production follows demand.

I have told (retold) the story of John Harrison and the marine chronometer because it illustrates some of the circumstances that condition the diffusion and invention of knowledge. In particular, it emphasizes the close links among comprehension (the ability to understand and absorb), application, opportunity, and the larger cognitive and social environment. Spain, for all its priority in oceanic navigation, was in no position to experiment and invent in this sphere. It lacked the craftsmen, in part because intelligence and skill gravitated in Spain to other, more honorific occupations. It lacked a base of interest and experience in time measurement, which was far more important to merchants and manufacturers (as in England) than to conquistadores, encomenderos, and caballeros; also, for a variety of reasons, to Protestants than to Catholics.

To be sure, John Harrison was something of a sport; his achievements testify to the importance of the personal, accidental factor in history. But his career was made possible by contacts with the world of science even in his isolated Lincolnshire village; and when he went to London, he found the kind of comprehension and support that come only with sympathy and knowledge. He was fortunate enough to find in George Graham, the leading watch- and clockmaker of the day, a man of uncommon generosity, of spirit as well as pocket. But Graham was not so exceptional that he does not convey something of the openness and mutual awareness that characterized the scientific and technological community of the time and place.[7]

All of this, in little, exemplifies the general characteristics of European technology from the Middle Ages. Away back then, in a time that historians had long portrayed as miserably poor and backward, Europeans were quick learners

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and improvers of techniques from any source. Building on a long-forgotten or neglected legacy of technique from classical antiquity, with additions imported by the so-called barbarians, or acquired from more advanced cultures to the east, they succeeded in developing by the fourteenth century—certainly by the fifteenth—a corpus of knowledge and skills that not only put them far ahead of their teachers, but conferred on them a decisive superiority of power. It is on this basis that Europe changed from a hapless victim to global aggressor, from a poor backwater, obliged to make its balance of payments in slaves for want of marketable exports, to the affluent workshop of the world.

The explanation of this extraordinary turnaround and the subsequent divergence of the West from the Rest is still a matter of inquiry and debate. The economic expansion and development in themselves have usually been accounted for in Smithian terms—as the natural consequence of restored order and security. Trade was advantageous, so the Europeans traded; the rest followed.

Even if this were enough to explain what Robert Lopez calls the commercial revolution of the Middle Ages, however, it will not tell whence this inventiveness, this growing interest in novelty, this cumulative emulation in ingenuity. Other societies have known moments of commercial prosperity and economic expansion, yet they have not taken this course of sustained technological advance.

Some of the answers to this question have stressed the special character of medieval political institutions. In *The Unbound Prometheus* I noted two of these. The first was the political fragmentation, which made for rivalry among competing units and led rulers to accept the alliance of the bourgeoisie, grant substantial autonomy to cities and towns (unknown anywhere else), and encourage and support those technicians, scientists, and artists whose work could redound to their prestige and advantage. Second, and related to the first, was the early recognition of rights of property, which afforded inventors and entrepreneurs security in the enjoyment of the fruits of their labor and wealth.[8] The contrast with other societies in this regard was striking. Listen to Sir Thomas Roe, ambassador of James I to the Mogul emperor in India (1615): "Lawes they have none written. The Kyngs judgement byndes. . . . His Governors of Provinces rule by his *Firmanes*. . . . They take life and goodes at pleasure . . ."[9]

Yet such factors are surely only part of the story; and, indeed, one would not have to be a Marxist to turn some of this around and argue that it was the successful bourgeoisie that made the property rights and not the reverse.

Another significant element of the story was the role of the Christian church, particularly the monastic orders, which constituted highly productive agricultural and industrial communities organized not for absolute self-sufficiency but for economic autonomy. Their ranks included some of the best mechanics and architects of the time; their shops were schools for skill and technique; and their dispersion throughout Europe was a strong force for the diffusion of knowledge.

Once again, though, the existence of the institution is not in itself an explanation. The question remains: Why this behavior, which contrasts sharply with that of other religions and even with the Eastern branch of the Christian

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faith. Without attempting a process of endless regression, the answer to that lies in the realm of values and attitudes: the choice of activism over the contemplative life (Martha over Mary), the Benedictine equation of work to prayer *(laborare est orare)*, a paradoxical concern to soften the pain of labor, the Judaic desacralization of nature, and others still to be explored.[10]

The values of the monastic orders were (became?) those of a creative minority of the population as a whole. Why this was so, I am not prepared to say: people learned from the Church; the Church learned from the people. Too many—the vast majority—of the inventors, innovators, and doers of the Middle Ages are unknown to us. But what has come down to us, largely as a result of recent research, is the sense of a growing community of savants and builders and mechanics *(homo faber)*, communicating with one another, copying and improving, climbing by standing on the shoulders of those who came before, tingling with the excitement of achievement. Lynn White cites a sermon preached by the Dominican Fra Giordano of Pisa in 1306, singing the praises of invention:

> Not all the arts have been found; we shall never see an end of finding them. Every day one could discover a new art . . . indeed they are being found all the time. It is not twenty years since there was discovered the art of making spectacles, which help you to see well and which is one of the best and most necessary in the world. And that is such a short time ago that a new art, which never before existed, was invented. . . . I myself saw the man who discovered and practiced it, and I talked with him.[11]

It is this turn of mind, this excitement and pleasure, this Faustian passion even within the bosom of the Church that goes far to account for the peculiarity of European technological development. For better and worse: the same impulse that gave us eyeglasses, and added years of useful study and work to some of the best minds and most skilled hands of the age, also gave us gunpowder and firearms. (The Chinese used powder in their fireworks; the Europeans borrowed it, improved it to increase its explosive force, and used it in cannon.) And it is this turn of mind—or some approximation to it—that I would argue is a prerequisite not only for the diffusion of technology, but the ability to generate technology in preindustrial societies.

What does that mean for the education in technology of the less developed countries, with which we began? I am afraid it may seem at first sight to imply a counsel of despair: if a society does not have the kind of spirit that generates technology, it will not absorb technique or knowledge. But social scientists, no less than natural scientists or engineers, do not like counsels of despair. They prefer to think that problems have solutions, that tasks are made to be done, hence, that the diffusion of technology is everywhere feasible. If the ability to assimilate and generate knowledge is linked to the value system of the society, why then, we must find ways to inculcate and nurture the right values.

Unfortunately, it has proved easier to transfer capital, materials, and labor than values or even knowledge. It is not hard to know what to teach; the questions are: How? To whom? On what level? Should we build a broad base?

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Concentrate on elites? Let me attempt some first approximations to answers on the basis of the Western experience.

1. There has been a shift from learning by doing to learning in school. The first centuries of European technological advance built on empirical experience. Apprentices learned at the bench, alongside trained workers and masters—the whole process often organized and regulated by craft guilds. Bench learning never disappeared—it is still important today—but from the eighteenth century on, it has been increasingly confined to skill-intensive branches of hand manufacture or to a complementary role, taking the products of school training and fitting them for the special demands of a given job.

The growing emphasis on school learning reflects, first, the changing content of technology: the newer branches of production especially (chemicals, say, or anything connected with electricity) use techniques more esoteric, less apprehensible by observation and common sense than the older branches (textiles, machine building, and so on). Second, schooling offers the possibility of training more people faster and for a wider range of activities. Bench learning tends to be job-specific; school learning can be adapted to a variety of applications. It is no wonder, then, that within Europe the so-called follower countries, those that wanted to emulate Britain in the course to industrialization, came to rely far more extensively than the British had on formal school instruction.

2. These educational programs have always been highly selective in character. They have built on a broad base of literacy and numeracy, but elementary schooling as such has been important, not for its direct contribution to economic performance, but as training in citizenship and as a device for the recruitment of talent. Other things being equal, the bigger the pool one draws from, the better the chances of finding gifted and original scientists and technicians.

3. The European achievement has always rested on a close alliance between science and technology, between theory and application. Indeed, until fairly recent times it would have made little sense to distinguish between those two modes. The scientists (that is, those whom we would call scientists) were invariably engaged in applications; indeed, derived most of their theoretical thought by reflecting on observation and experience. The technicians drew on what they knew of the corpus of scientific knowledge and added to it by study (like Harrison) and personal consultation. Even after scientific training and procedure separated themselves from application and engineering, and so-called pure science was set aside (above?) as something special, the old ties remained important. Industry in advanced countries has continued to treat faculties of science as an intellectual resource; and these same faculties have given numerous gifted students and teachers to the ranks of industry and enterprise.

4. European performance owed much to an atmosphere of competition and emulation. There have always been multiple points of initiative, of creation, imitation, improvement. This was only partly due to the political fragmentation; it was also inextricably tied to a system of free enterprise.

5. This atmosphere of competition and emulation has been, in my opinion, a most powerful force for the sustained enthusiasm, even joy, of the European

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(Western, Japanese) research effort. Because of it, the pursuit of knowledge and its application have yielded great psychic as well as material rewards. We may still not be able to account for the origin of this *Neuerungsfreudigkeit*, this joy in novelty, but its persistence clearly owes much to its agonistic character.

What are the lessons in all this for the less developed countries of today? Their principal weakness lies in their inability to find the equivalents of competition and enthusiasm. The first three conditions are difficult enough, but at least one can see there the outline of an educational strategy. But the latter conditions are as much political as economic and fly in the face of all the prevailing trends and predilections. To be sure, it is not hard to postulate nonmarket (socialistic) substitutes for the stimuli and incentives of freedom and competition: loyalty to a social or national ideal (also present in a market economy such as Japan); bestowal of awards and rewards from above (the Legion of Honor or the numerous Soviet prizes and privileges); to say nothing of the power of a disinterested curiosity and creative energy.

But all of that is a promissory note without a maturity date. The historical record shows that, so far, the only nations that have generated an autonomous and creative technology have been those characterized by freedom of initiative and enterprise. The one apparent exception, the Soviet Union, was able to build on a substantial educational and industrial base inherited from the Old Regime. China may yet prove to be a second exception, though it too has had much more to work with than most of the less developed countries in Asia and Africa.[12]

These have their task cut out for them. We can help, but in the last analysis, this is one aspect of growth and development that each society has to accomplish by itself, from within.

REFERENCES

[1]Oceanic navigation goes back earlier, of course. But these voyages were the product of accident or feats of derring-do, with the exception of the Norse leaps to Iceland and Greenland and archipelagic travel in the Pacific. It was only with the establishment of normal trading and administrative connections to Asia and America that one can speak of oceanic sailing as a continuing, regular activity.

[2]Later, this technique was much improved by making use of a log and sand clock. The log was thrown astern and unwound a rope tied with knots at regular intervals. At the end of the time marked by the sand clock (far more accurate, obviously, than some verbal formula), the knots run out were counted and converted to speed, that is, distance over time. To this day the knot continues as a measure of nautical speed.

[3]*The Correspondence of Isaac Newton*, vol. 7 (Cambridge, 1977), p. 172, cited by Will Andrewes, "John Harrison: A Study of His Early Work," *Horological Dialogues* (Journal of the American Section, Antiquarian Horological Society), I (1979), 37, n. 3.

[4]This was not enough to get him the prize: where so much money was at stake, the Board of Longitude was reluctant to pay out until assured that the results were not a fluke and that the instrument could be replicated; besides, the chairman of the Board, the Astronomer-Royal Maskelyne, was a determined advocate of an astronomical method of calculating longitude, the so-called method of lunar distances. It took more than a decade for Harrison to collect his due, and he succeeded only because of the personal intervention of King George, himself an amateur clock- and watchmaker. Cf. Rupert T. Gould, *The Marine Chronometer: Its History and Development* (2d ed.; London, 1960), pp. 56-70.

[5]The major exception was his system of "maintaining power"—a means of keeping up tension, hence the going rate, of timekeepers during winding.

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[6]The actual escapement used in just about every instrument made from 1800 was Earnshaw's version.

[7]Graham, though, like Harrison, was a craftsman and technician. An astronomer such as Maskelyne had less confidence in the mechanical arts, and was reluctant to accept a nonastronomical solution to the longitude problem. This kind of intellectual snobbery is a recurrent aspect of the European scientific tradition—though more in some places and times than others. Nineteenth century Germany is a particularly striking example. But it would have made little sense to such scientific greats as Galileo, Hooke, or Huygens, all of whom worked closely with gifted instrument makers who gave as well as took in the exchange.

[8]The latter point has since been made by Douglass North and Robert P. Thomas, the keystone of their analysis of European economic development. See *The Rise of the Western World: A New Economic History* (Cambridge, 1973).

[9]Wm. Foster (ed.), *The Embassy of Sir Thomas Roe to the Court of the Great Mogul, 1615-1619* (2 vols.; London: Hakluyt Society, 1899), I, 123.

[10]See especially Lynn White, Jr., "Cultural Climates and Technological Advance in the Middle Ages," *Viator: Medieval and Renaissance Studies, 2* (1971): 171-201.

[11]*Ibid.*, p. 174.

[12]In this regard, note the recent Chinese development of the technology and manufacture of optical fibers, "virtually without outside help." "Jumping a Century," *The Economist*, 273 (7107) (Nov. 17, 1979): 105-6.

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LANGDON WINNER

Do Artifacts Have Politics?

IN CONTROVERSIES ABOUT TECHNOLOGY AND SOCIETY, there is no idea more provocative than the notion that technical things have political qualities. At issue is the claim that the machines, structures, and systems of modern material culture can be accurately judged not only for their contributions of efficiency and productivity, not merely for their positive and negative environmental side effects, but also for the ways in which they can embody specific forms of power and authority. Since ideas of this kind have a persistent and troubling presence in discussions about the meaning of technology, they deserve explicit attention.[1]

Writing in *Technology and Culture* almost two decades ago, Lewis Mumford gave classic statement to one version of the theme, arguing that "from late neolithic times in the Near East, right down to our own day, two technologies have recurrently existed side by side: one authoritarian, the other democratic, the first system-centered, immensely powerful, but inherently unstable, the other man-centered, relatively weak, but resourceful and durable."[2] This thesis stands at the heart of Mumford's studies of the city, architecture, and the history of technics, and mirrors concerns voiced earlier in the works of Peter Kropotkin, William Morris, and other nineteenth century critics of industrialism. More recently, antinuclear and prosolar energy movements in Europe and America have adopted a similar notion as a centerpiece in their arguments. Thus environmentalist Denis Hayes concludes, "The increased deployment of nuclear power facilities must lead society toward authoritarianism. Indeed, safe reliance upon nuclear power as the principal source of energy may be possible only in a totalitarian state." Echoing the views of many proponents of appropriate technology and the soft energy path, Hayes contends that "dispersed solar sources are more compatible than centralized technologies with social equity, freedom and cultural pluralism."[3]

An eagerness to interpret technical artifacts in political language is by no means the exclusive property of critics of large-scale high-technology systems. A long lineage of boosters have insisted that the "biggest and best" that science and industry made available were the best guarantees of democracy, freedom, and social justice. The factory system, automobile, telephone, radio, television, the space program, and of course nuclear power itself have all at one time or another been described as democratizing, liberating forces. David Lilienthal, in *T.V.A.: Democracy on the March,* for example, found this promise in the phos-

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phate fertilizers and electricity that technical progress was bringing to rural Americans during the 1940s.[4] In a recent essay, *The Republic of Technology*, Daniel Boorstin extolled television for "its power to disband armies, to cashier presidents, to create a whole new democratic world—democratic in ways never before imagined, even in America."[5] Scarcely a new invention comes along that someone does not proclaim it the salvation of a free society.

It is no surprise to learn that technical systems of various kinds are deeply interwoven in the conditions of modern politics. The physical arrangements of industrial production, warfare, communications, and the like have fundamentally changed the exercise of power and the experience of citizenship. But to go beyond this obvious fact and to argue that certain technologies *in themselves* have political properties seems, at first glance, completely mistaken. We all know that people have politics, not things. To discover either virtues or evils in aggregates of steel, plastic, transistors, integrated circuits, and chemicals seems just plain wrong, a way of mystifying human artifice and of avoiding the true sources, the human sources of freedom and oppression, justice and injustice. Blaming the hardware appears even more foolish than blaming the victims when it comes to judging conditions of public life.

Hence, the stern advice commonly given those who flirt with the notion that technical artifacts have political qualities: What matters is not technology itself, but the social or economic system in which it is embedded. This maxim, which in a number of variations is the central premise of a theory that can be called the social determination of technology, has an obvious wisdom. It serves as a needed corrective to those who focus uncritically on such things as "the computer and its social impacts" but who fail to look behind technical things to notice the social circumstances of their development, deployment, and use. This view provides an antidote to naive technological determinism—the idea that technology develops as the sole result of an internal dynamic, and then, unmediated by any other influence, molds society to fit its patterns. Those who have not recognized the ways in which technologies are shaped by social and economic forces have not gotten very far.

But the corrective has its own shortcomings; taken literally, it suggests that technical *things* do not matter at all. Once one has done the detective work necessary to reveal the social origins—power holders behind a particular instance of technological change—one will have explained everything of importance. This conclusion offers comfort to social scientists: it validates what they had always suspected, namely, that there is nothing distinctive about the study of technology in the first place. Hence, they can return to their standard models of social power—those of interest group politics, bureaucratic politics, Marxist models of class struggle, and the like—and have everything they need. The social determination of technology is, in this view, essentially no different from the social determination of, say, welfare policy or taxation.

There are, however, good reasons technology has of late taken on a special fascination in its own right for historians, philosophers, and political scientists; good reasons the standard models of social science only go so far in accounting for what is most interesting and troublesome about the subject. In another place I have tried to show why so much of modern social and political thought contains recurring statements of what can be called a theory of tech-

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nological politics, an odd mongrel of notions often crossbred with orthodox liberal, conservative, and socialist philosophies.[6] The theory of technological politics draws attention to the momentum of large-scale sociotechnical systems, to the response of modern societies to certain technological imperatives, and to the all too common signs of the adaptation of human ends to technical means. In so doing it offers a novel framework of interpretation and explanation for some of the more puzzling patterns that have taken shape in and around the growth of modern material culture. One strength of this point of view is that it takes technical artifacts seriously. Rather than insist that we immediately reduce everything to the interplay of social forces, it suggests that we pay attention to the characteristics of technical objects and the meaning of those characteristics. A necessary complement to, rather than a replacement for, theories of the social determination of technology, this perspective identifies certain technologies as political phenomena in their own right. It points us back, to borrow Edmund Husserl's philosophical injunction, *to the things themselves.*

In what follows I shall offer outlines and illustrations of two ways in which artifacts can contain political properties. First are instances in which the invention, design, or arrangement of a specific technical device or system becomes a way of settling an issue in a particular community. Seen in the proper light, examples of this kind are fairly straightforward and easily understood. Second are cases of what can be called inherently political technologies, man-made systems that appear to require, or to be strongly compatible with, particular kinds of political relationships. Arguments about cases of this kind are much more troublesome and closer to the heart of the matter. By "politics," I mean arrangements of power and authority in human associations as well as the activities that take place within those arrangements. For my purposes, "technology" here is understood to mean all of modern practical artifice,[7] but to avoid confusion I prefer to speak of technologies, smaller or larger pieces or systems of hardware of a specific kind. My intention is not to settle any of the issues here once and for all, but to indicate their general dimensions and significance.

Technical Arrangements as Forms of Order

Anyone who has traveled the highways of America and has become used to the normal height of overpasses may well find something a little odd about some of the bridges over the parkways on Long Island, New York. Many of the overpasses are extraordinarily low, having as little as nine feet of clearance at the curb. Even those who happened to notice this structural peculiarity would not be inclined to attach any special meaning to it. In our accustomed way of looking at things like roads and bridges we see the details of form as innocuous, and seldom give them a second thought.

It turns out, however, that the two hundred or so low-hanging overpasses on Long Island were deliberately designed to achieve a particular social effect. Robert Moses, the master builder of roads, parks, bridges, and other public works from the 1920s to the 1970s in New York, had these overpasses built to specifications that would discourage the presence of buses on his parkways. According to evidence provided by Robert A. Caro in his biography of Moses, the reasons reflect Moses's social-class bias and racial prejudice. Automobile-

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owning whites of "upper" and "comfortable middle" classes, as he called them, would be free to use the parkways for recreation and commuting. Poor people and blacks, who normally used public transit, were kept off the roads because the twelve-foot tall buses could not get through the overpasses. One consequence was to limit access of racial minorities and low-income groups to Jones Beach, Moses's widely acclaimed public park. Moses made doubly sure of this result by vetoing a proposed extension of the Long Island Railroad to Jones Beach.[8]

As a story in recent American political history, Robert Moses's life is fascinating. His dealings with mayors, governors, and presidents, and his careful manipulation of legislatures, banks, labor unions, the press, and public opinion are all matters that political scientists could study for years. But the most important and enduring results of his work are his technologies, the vast engineering projects that give New York much of its present form. For generations after Moses has gone and the alliances he forged have fallen apart, his public works, especially the highways and bridges he built to favor the use of the automobile over the development of mass transit, will continue to shape that city. Many of his monumental structures of concrete and steel embody a systematic social inequality, a way of engineering relationships among people that, after a time, becomes just another part of the landscape. As planner Lee Koppleman told Caro about the low bridges on Wantagh Parkway, "The old son-of-a-gun had made sure that buses would *never* be able to use his goddamned parkways."[9]

Histories of architecture, city planning, and public works contain many examples of physical arrangements that contain explicit or implicit political purposes. One can point to Baron Haussmann's broad Parisian thoroughfares, engineered at Louis Napoleon's direction to prevent any recurrence of street fighting of the kind that took place during the revolution of 1848. Or one can visit any number of grotesque concrete buildings and huge plazas constructed on American university campuses during the late 1960s and early 1970s to defuse student demonstrations. Studies of industrial machines and instruments also turn up interesting political stories, including some that violate our normal expectations about why technological innovations are made in the first place. If we suppose that new technologies are introduced to achieve increased efficiency, the history of technology shows that we will sometimes be disappointed. Technological change expresses a panoply of human motives, not the least of which is the desire of some to have dominion over others, even though it may require an occasional sacrifice of cost-cutting and some violence to the norm of getting more from less.

One poignant illustration can be found in the history of nineteenth century industrial mechanization. At Cyrus McCormick's reaper manufacturing plant in Chicago in the middle 1880s, pneumatic molding machines, a new and largely untested innovation, were added to the foundry at an estimated cost of $500,000. In the standard economic interpretation of such things, we would expect that this step was taken to modernize the plant and achieve the kind of efficiencies that mechanization brings. But historian Robert Ozanne has shown why the development must be seen in a broader context. At the time, Cyrus McCormick II was engaged in a battle with the National Union of Iron Molders. He saw the addition of the new machines as a way to "weed out the bad

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element among the men," namely, the skilled workers who had organized the union local in Chicago.[10] The new machines, manned by unskilled labor, actually produced inferior castings at a higher cost than the earlier process. After three years of use the machines were, in fact, abandoned, but by that time they had served their purpose—the destruction of the union. Thus, the story of these technical developments at the McCormick factory cannot be understood adequately outside the record of workers' attempts to organize, police repression of the labor movement in Chicago during that period, and the events surrounding the bombing at Haymarket Square. Technological history and American political history were at that moment deeply intertwined.

In cases like those of Moses's low bridges and McCormick's molding machines, one sees the importance of technical arrangements that precede the *use* of the things in question. It is obvious that technologies can be used in ways that enhance the power, authority, and privilege of some over others, for example, the use of television to sell a candidate. To our accustomed way of thinking, technologies are seen as neutral tools that can be used well or poorly, for good, evil, or something in between. But we usually do not stop to inquire whether a given device might have been designed and built in such a way that it produces a set of consequences logically and temporally *prior* to any of its professed uses. Robert Moses's bridges, after all, were used to carry automobiles from one point to another; McCormick's machines were used to make metal castings; both technologies, however, encompassed purposes far beyond their immediate use. If our moral and political language for evaluating technology includes only categories having to do with tools and uses, if it does not include attention to the meaning of the designs and arrangements of our artifacts, then we will be blinded to much that is intellectually and practically crucial.

Because the point is most easily understood in the light of particular intentions embodied in physical form, I have so far offered illustrations that seem almost conspiratorial. But to recognize the political dimensions in the shapes of technology does not require that we look for conscious conspiracies or malicious intentions. The organized movement of handicapped people in the United States during the 1970s pointed out the countless ways in which machines, instruments, and structures of common use—buses, buildings, sidewalks, plumbing fixtures, and so forth—made it impossible for many handicapped persons to move about freely, a condition that systematically excluded them from public life. It is safe to say that designs unsuited for the handicapped arose more from long-standing neglect than from anyone's active intention. But now that the issue has been raised for public attention, it is evident that justice requires a remedy. A whole range of artifacts are now being redesigned and rebuilt to accommodate this minority.

Indeed, many of the most important examples of technologies that have political consequences are those that transcend the simple categories of "intended" and "unintended" altogether. These are instances in which the very process of technical development is so thoroughly biased in a particular direction that it regularly produces results counted as wonderful breakthroughs by some social interests and crushing setbacks by others. In such cases it is neither correct nor insightful to say, "Someone intended to do somebody else harm." Rather, one must say that the technological deck has been stacked long in ad-

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vance to favor certain social interests, and that some people were bound to receive a better hand than others.

The mechanical tomato harvester, a remarkable device perfected by researchers at the University of California from the late 1940s to the present, offers an illustrative tale. The machine is able to harvest tomatoes in a single pass through a row, cutting the plants from the ground, shaking the fruit loose, and in the newest models sorting the tomatoes electronically into large plastic gondolas that hold up to twenty-five tons of produce headed for canning. To accommodate the rough motion of these "factories in the field," agricultural researchers have bred new varieties of tomatoes that are hardier, sturdier, and less tasty. The harvesters replace the system of handpicking, in which crews of farmworkers would pass through the fields three or four times putting ripe tomatoes in lug boxes and saving immature fruit for later harvest.[11] Studies in California indicate that the machine reduces costs by approximately five to seven dollars per ton as compared to hand-harvesting.[12] But the benefits are by no means equally divided in the agricultural economy. In fact, the machine in the garden has in this instance been the occasion for a thorough reshaping of social relationships of tomato production in rural California.

By their very size and cost, more than $50,000 each to purchase, the machines are compatible only with a highly concentrated form of tomato growing. With the introduction of this new method of harvesting, the number of tomato growers declined from approximately four thousand in the early 1960s to about six hundred in 1973, yet with a substantial increase in tons of tomatoes produced. By the late 1970s an estimated thirty-two thousand jobs in the tomato industry had been eliminated as a direct consequence of mechanization.[13] Thus, a jump in productivity to the benefit of very large growers has occurred at a sacrifice to other rural agricultural communities.

The University of California's research and development on agricultural machines like the tomato harvester is at this time the subject of a law suit filed by attorneys for California Rural Legal Assistance, an organization representing a group of farmworkers and other interested parties. The suit charges that University officials are spending tax monies on projects that benefit a handful of private interests to the detriment of farmworkers, small farmers, consumers, and rural California generally, and asks for a court injunction to stop the practice. The University has denied these charges, arguing that to accept them "would require elimination of all research with any potential practical application."[14]

As far as I know, no one has argued that the development of the tomato harvester was the result of a plot. Two students of the controversy, William Friedland and Amy Barton, specifically exonerate both the original developers of the machine and the hard tomato from any desire to facilitate economic concentration in that industry.[15] What we see here instead is an ongoing social process in which scientific knowledge, technological invention, and corporate profit reinforce each other in deeply entrenched patterns that bear the unmistakable stamp of political and economic power. Over many decades agricultural research and development in American land-grant colleges and universities has tended to favor the interests of large agribusiness concerns.[16] It is in the face of such subtly ingrained patterns that opponents of innovations like the tomato

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harvester are made to seem "antitechnology" or "antiprogress." For the harvester is not merely the symbol of a social order that rewards some while punishing others; it is in a true sense an embodiment of that order.

Within a given category of technological change there are, roughly speaking, two kinds of choices that can affect the relative distribution of power, authority, and privilege in a community. Often the crucial decision is a simple "yes or no" choice—are we going to develop and adopt the thing or not? In recent years many local, national, and international disputes about technology have centered on "yes or no" judgments about such things as food additives, pesticides, the building of highways, nuclear reactors, and dam projects. The fundamental choice about an ABM or an SST is whether or not the thing is going to join society as a piece of its operating equipment. Reasons for and against are frequently as important as those concerning the adoption of an important new law.

A second range of choices, equally critical in many instances, has to do with specific features in the design or arrangement of a technical system after the decision to go ahead with it has already been made. Even after a utility company wins permission to build a large electric power line, important controversies can remain with respect to the placement of its route and the design of its towers; even after an organization has decided to institute a system of computers, controversies can still arise with regard to the kinds of components, programs, modes of access, and other specific features the system will include. Once the mechanical tomato harvester had been developed in its basic form, design alteration of critical social significance—the addition of electronic sorters, for example—changed the character of the machine's effects on the balance of wealth and power in California agriculture. Some of the most interesting research on technology and politics at present focuses on the attempt to demonstrate in a detailed, concrete fashion how seemingly innocuous design features in mass transit systems, water projects, industrial machinery, and other technologies actually mask social choices of profound significance. Historian David Noble is now studying two kinds of automated machine tool systems that have different implications for the relative power of management and labor in the industries that might employ them. He is able to show that, although the basic electronic and mechanical components of the record/playback and numerical control systems are similar, the choice of one design over another has crucial consequences for social struggles on the shop floor. To see the matter solely in terms of cost-cutting, efficiency, or the modernization of equipment is to miss a decisive element in the story.[17]

From such examples I would offer the following general conclusions. The things we call "technologies" are ways of building order in our world. Many technical devices and systems important in everyday life contain possibilities for many different ways of ordering human activity. Consciously or not, deliberately or inadvertently, societies choose structures for technologies that influence how people are going to work, communicate, travel, consume, and so forth over a very long time. In the processes by which structuring decisions are made, different people are differently situated and possess unequal degrees of power as well as unequal levels of awareness. By far the greatest latitude of choice exists the very first time a particular instrument, system, or technique is introduced. Because choices tend to become strongly fixed in material equipment, economic

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investment, and social habit, the original flexibility vanishes for all practical purposes once the initial commitments are made. In that sense technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations. For that reason, the same careful attention one would give to the rules, roles, and relationships of politics must also be given to such things as the building of highways, the creation of television networks, and the tailoring of seemingly insignificant features on new machines. The issues that divide or unite people in society are settled not only in the institutions and practices of politics proper, but also, and less obviously, in tangible arrangements of steel and concrete, wires and transistors, nuts and bolts.

Inherently Political Technologies

None of the arguments and examples considered thus far address a stronger, more troubling claim often made in writings about technology and society—the belief that some technologies are by their very nature political in a specific way. According to this view, the adoption of a given technical system unavoidably brings with it conditions for human relationships that have a distinctive political cast—for example, centralized or decentralized, egalitarian or inegalitarian, repressive or liberating. This is ultimately what is at stake in assertions like those of Lewis Mumford that two traditions of technology, one authoritarian, the other democratic, exist side by side in Western history. In all the cases I cited above the technologies are relatively flexible in design and arrangement, and variable in their effects. Although one can recognize a particular result produced in a particular setting, one can also easily imagine how a roughly similar device or system might have been built or situated with very much different political consequences. The idea we must now examine and evaluate is that certain kinds of technology do not allow such flexibility, and that to choose them is to choose a particular form of political life.

A remarkably forceful statement of one version of this argument appears in Friedrich Engels's little essay "On Authority" written in 1872. Answering anarchists who believed that authority is an evil that ought to be abolished altogether, Engels launches into a panegyric for authoritarianism, maintaining, among other things, that strong authority is a necessary condition in modern industry. To advance his case in the strongest possible way, he asks his readers to imagine that the revolution has already occurred. "Supposing a social revolution dethroned the capitalists, who now exercise their authority over the production and circulation of wealth. Supposing, to adopt entirely the point of view of the anti-authoritarians, that the land and the instruments of labour had become the collective property of the workers who use them. Will authority have disappeared or will it have only changed its form?"[18]

His answer draws upon lessons from three sociotechnical systems of his day, cotton-spinning mills, railways, and ships at sea. He observes that, on its way to becoming finished thread, cotton moves through a number of different operations at different locations in the factory. The workers perform a wide variety of tasks, from running the steam engine to carrying the products from one room to another. Because these tasks must be coordinated, and because the timing of the work is "fixed by the authority of the steam," laborers must learn to accept a

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rigid discipline. They must, according to Engels, work at regular hours and agree to subordinate their individual wills to the persons in charge of factory operations. If they fail to do so, they risk the horrifying possibility that production will come to a grinding halt. Engels pulls no punches. "The automatic machinery of a big factory," he writes, "is much more despotic than the small capitalists who employ workers ever have been."[19]

Similar lessons are adduced in Engels's analysis of the necessary operating conditions for railways and ships at sea. Both require the subordination of workers to an "imperious authority" that sees to it that things run according to plan. Engels finds that, far from being an idiosyncracy of capitalist social organization, relationships of authority and subordination arise "independently of all social organization, [and] are imposed upon us together with the material conditions under which we produce and make products circulate." Again, he intends this to be stern advice to the anarchists who, according to Engels, thought it possible simply to eradicate subordination and superordination at a single stroke. All such schemes are nonsense. The roots of unavoidable authoritarianism are, he argues, deeply implanted in the human involvement with science and technology. "If man, by dint of his knowledge and inventive genius, has subdued the forces of nature, the latter avenge themselves upon him by subjecting him, insofar as he employs them, to a veritable despotism independent of all social organization."[20]

Attempts to justify strong authority on the basis of supposedly necessary conditions of technical practice have an ancient history. A pivotal theme in the *Republic* is Plato's quest to borrow the authority of *technē* and employ it by analogy to buttress his argument in favor of authority in the state. Among the illustrations he chooses, like Engels, is that of a ship on the high seas. Because large sailing vessels by their very nature need to be steered with a firm hand, sailors must yield to their captain's commands; no reasonable person believes that ships can be run democratically. Plato goes on to suggest that governing a state is rather like being captain of a ship or like practicing medicine as a physician. Much the same conditions that require central rule and decisive action in organized technical activity also create this need in government.

In Engels's argument, and arguments like it, the justification for authority is no longer made by Plato's classic analogy, but rather directly with reference to technology itself. If the basic case is as compelling as Engels believed it to be, one would expect that, as a society adopted increasingly complicated technical systems as its material basis, the prospects for authoritarian ways of life would be greatly enhanced. Central control by knowledgeable people acting at the top of a rigid social hierarchy would seem increasingly prudent. In this respect, his stand in "On Authority" appears to be at variance with Karl Marx's position in Volume One of *Capital*. Marx tries to show that increasing mechanization will render obsolete the hierarchical division of labor and the relationships of subordination that, in his view, were necessary during the early stages of modern manufacturing. The "Modern Industry," he writes, ". . . sweeps away by technical means the manufacturing division of labor, under which each man is bound hand and foot for life to a single detail operation. At the same time, the capitalistic form of that industry reproduces this same division of labour in a still more monstrous shape; in the factory proper, by converting the workman into a living appendage of the machine. . . ."[21] In Marx's view, the conditions

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that will eventually dissolve the capitalist division of labor and facilitate proletarian revolution are conditions latent in industrial technology itself. The differences between Marx's position in *Capital* and Engels's in his essay raise an important question for socialism: What, after all, does modern technology make possible or necessary in political life? The theoretical tension we see here mirrors many troubles in the practice of freedom and authority that have muddied the tracks of socialist revolution.

Arguments to the effect that technologies are in some sense inherently political have been advanced in a wide variety of contexts, far too many to summarize here. In my reading of such notions, however, there are two basic ways of stating the case. One version claims that the adoption of a given technical system actually *requires* the creation and maintenance of a particular set of social conditions as the operating environment of that system. Engels's position is of this kind. A similar view is offered by a contemporary writer who holds that "if you accept nuclear power plants, you also accept a techno-scientific-industrial-military elite. Without these people in charge, you could not have nuclear power."[29] In this conception, some kinds of technology require their social environments to be structured in a particular way in much the same sense that an automobile requires wheels in order to run. The thing could not exist as an effective operating entity unless certain social as well as material conditions were met. The meaning of "required" here is that of practical (rather than logical) necessity. Thus, Plato thought it a practical necessity that a ship at sea have one captain and an unquestioningly obedient crew.

A second, somewhat weaker, version of the argument holds that a given kind of technology is strongly *compatible with*, but does not strictly require, social and political relationships of a particular stripe. Many advocates of solar energy now hold that technologies of that variety are more compatible with a democratic, egalitarian society than energy systems based on coal, oil, and nuclear power; at the same time they do not maintain that anything about solar energy requires democracy. Their case is, briefly, that solar energy is decentralizing in both a technical and political sense: technically speaking, it is vastly more reasonable to build solar systems in a disaggregated, widely distributed manner than in large-scale centralized plants; politically speaking, solar energy accommodates the attempts of individuals and local communities to manage their affairs effectively because they are dealing with systems that are more accessible, comprehensible, and controllable than huge centralized sources. In this view, solar energy is desirable not only for its economic and environmental benefits, but also for the salutary institutions it is likely to permit in other areas of public life.[23]

Within both versions of the argument there is a further distinction to be made between conditions that are *internal* to the workings of a given technical system and those that are *external* to it. Engels's thesis concerns internal social relations said to be required within cotton factories and railways, for example; what such relationships mean for the condition of society at large is for him a separate question. In contrast, the solar advocate's belief that solar technologies are compatible with democracy pertains to the way they complement aspects of society removed from the organization of those technologies as such.

There are, then, several different directions that arguments of this kind can follow. Are the social conditions predicated said to be required by, or strongly

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compatible with, the workings of a given technical system? Are those conditions internal to that system or external to it (or both)? Although writings that address such questions are often unclear about what is being asserted, arguments in this general category do have an important presence in modern political discourse. They enter into many attempts to explain how changes in social life take place in the wake of technological innovation. More importantly, they are often used to buttress attempts to justify or criticize proposed courses of action involving new technology. By offering distinctly political reasons for or against the adoption of a particular technology, arguments of this kind stand apart from more commonly employed, more easily quantifiable claims about economic costs and benefits, environmental impacts, and possible risks to public health and safety that technical systems may involve. The issue here does not concern how many jobs will be created, how much income generated, how many pollutants added, or how many cancers produced. Rather, the issue has to do with ways in which choices about technology have important consequences for the form and quality of human associations.

If we examine social patterns that comprise the environments of technical systems, we find certain devices and systems almost invariably linked to specific ways of organizing power and authority. The important question is: Does this state of affairs derive from an unavoidable social response to intractable properties in the things themselves, or is it instead a pattern imposed independently by a governing body, ruling class, or some other social or cultural institution to further its own purposes?

Taking the most obvious example, the atom bomb is an inherently political artifact. As long as it exists at all, its lethal properties demand that it be controlled by a centralized, rigidly hierarchical chain of command closed to all influences that might make its workings unpredictable. The internal social system of the bomb must be authoritarian; there is no other way. The state of affairs stands as a practical necessity independent of any larger political system in which the bomb is embedded, independent of the kind of regime or character of its rulers. Indeed, democratic states must try to find ways to ensure that the social structures and mentality that characterize the management of nuclear weapons do not "spin off" or "spill over" into the polity as a whole.

The bomb is, of course, a special case. The reasons very rigid relationships of authority are necessary in its immediate presence should be clear to anyone. If, however, we look for other instances in which particular varieties of technology are *widely perceived* to need the maintenance of a special pattern of power and authority, modern technical history contains a wealth of examples.

Alfred D. Chandler in *The Visible Hand*, a monumental study of modern business enterprise, presents impressive documentation to defend the hypothesis that the construction and day-to-day operation of many systems of production, transportation, and communication in the nineteenth and twentieth centuries require the development of a particular social form—a large-scale centralized, hierarchical organization administered by highly skilled managers. Typical of Chandler's reasoning is his analysis of the growth of the railroads.

> Technology made possible fast, all-weather transportation; but safe, regular, reliable movement of goods and passengers, as well as the continuing maintenance and repair of locomotives, rolling stock, and track, roadbed, stations, round-

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> houses, and other equipment, required the creation of a sizable administrative organization. It meant the employment of a set of managers to supervise these functional activities over an extensive geographical area; and the appointment of an administrative command of middle and top executives to monitor, evaluate, and coordinate the work of managers responsible for the day-to-day operations.

Throughout his book Chandler points to ways in which technologies used in the production and distribution of electricity, chemicals, and a wide range of industrial goods "demanded" or "required" this form of human association. "Hence, the operational requirements of railroads demanded the creation of the first administrative hierarchies in American business."[25]

Were there other conceivable ways of organizing these aggregates of people and apparatus? Chandler shows that a previously dominant social form, the small traditional family firm, simply could not handle the task in most cases. Although he does not speculate further, it is clear that he believes there is, to be realistic, very little latitude in the forms of power and authority appropriate within modern sociotechnical systems. The properties of many modern technologies—oil pipelines and refineries, for example—are such that overwhelmingly impressive economies of scale and speed are possible. If such systems are to work effectively, efficiently, quickly, and safely, certain requirements of internal social organization have to be fulfilled; the material possibilities that modern technologies make available could not be exploited otherwise. Chandler acknowledges that as one compares sociotechnical institutions of different nations, one sees "ways in which cultural attitudes, values, ideologies, political systems, and social structure affect these imperatives."[26] But the weight of argument and empirical evidence in *The Visible Hand* suggests that any significant departure from the basic pattern would be, at best, highly unlikely.

It may be that other conceivable arrangements of power and authority, for example, those of decentralized, democratic worker self-management, could prove capable of administering factories, refineries, communications systems, and railroads as well as or better than the organizations Chandler describes. Evidence from automobile assembly teams in Sweden and worker-managed plants in Yugoslavia and other countries is often presented to salvage these possibilities. I shall not be able to settle controversies over this matter here, but merely point to what I consider to be their bone of contention. The available evidence tends to show that many large, sophisticated technological systems are in fact highly compatible with centralized, hierarchical managerial control. The interesting question, however, has to do with whether or not this pattern is in any sense a requirement of such systems, a question that is not solely an empirical one. The matter ultimately rests on our judgments about what steps, if any, are practically necessary in the workings of particular kinds of technology and what, if anything, such measures require of the structure of human associations. Was Plato right in saying that a ship at sea needs steering by a decisive hand and that this could only be accomplished by a single captain and an obedient crew? Is Chandler correct in saying that the properties of large-scale systems require centralized, hierarchical managerial control?

To answer such questions, we would have to examine in some detail the moral claims of practical necessity (including those advocated in the doctrines of

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economics) and weigh them against moral claims of other sorts, for example, the notion that it is good for sailors to participate in the command of a ship or that workers have a right to be involved in making and administering decisions in a factory. It is characteristic of societies based on large, complex technological systems, however, that moral reasons other than those of practical necessity appear increasingly obsolete, "idealistic," and irrelevant. Whatever claims one may wish to make on behalf of liberty, justice, or equality can be immediately neutralized when confronted with arguments to the effect: "Fine, but that's no way to run a railroad" (or steel mill, or airline, or communications system, and so on). Here we encounter an important quality in modern political discourse and in the way people commonly think about what measures are justified in response to the possibilities technologies make available. In many instances, to say that some technologies are inherently political is to say that certain widely accepted reasons of practical necessity—especially the need to maintain crucial technological systems as smoothly working entities—have tended to eclipse other sorts of moral and political reasoning.

One attempt to salvage the autonomy of politics from the bind of practical necessity involves the notion that conditions of human association found in the internal workings of technological systems can easily be kept separate from the polity as a whole. Americans have long rested content in the belief that arrangements of power and authority inside industrial corporations, public utilities, and the like have little bearing on public institutions, practices, and ideas at large. That "democracy stops at the factory gates" was taken as a fact of life that had nothing to do with the practice of political freedom. But can the internal politics of technology and the politics of the whole community be so easily separated? A recent study of American business leaders, contemporary exemplars of Chandler's "visible hand of management," found them remarkably impatient with such democratic scruples as "one man, one vote." If democracy doesn't work for the firm, the most critical institution in all of society, American executives ask, how well can it be expected to work for the government of a nation—particularly when that government attempts to interfere with the achievements of the firm? The authors of the report observe that patterns of authority that work effectively in the corporation become for businessmen "the desirable model against which to compare political and economic relationships in the rest of society."[27] While such findings are far from conclusive, they do reflect a sentiment increasingly common in the land: what dilemmas like the energy crisis require is not a redistribution of wealth or broader public participation but, rather, stronger, centralized public management—President Carter's proposal for an Energy Mobilization Board and the like.

An especially vivid case in which the operational requirements of a technical system might influence the quality of public life is now at issue in debates about the risks of nuclear power. As the supply of uranium for nuclear reactors runs out, a proposed alternative fuel is the plutonium generated as a by-product in reactor cores. Well-known objections to plutonium recycling focus on its unacceptable economic costs, its risks of environmental contamination, and its dangers in regard to the international proliferation of nuclear weapons. Beyond these concerns, however, stands another less widely appreciated set of hazards—those that involve the sacrifice of civil liberties. The widespread use of

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plutonium as a fuel increases the chance that this toxic substance might be stolen by terrorists, organized crime, or other persons. This raises the prospect, and not a trivial one, that extraordinary measures would have to be taken to safeguard plutonium from theft and to recover it if ever the substance were stolen. Workers in the nuclear industry as well as ordinary citizens outside could well become subject to background security checks, covert surveillance, wiretapping, informers, and even emergency measures under martial law—all justified by the need to safeguard plutonium.

Russell W. Ayres's study of the legal ramifications of plutonium recycling concludes: "With the passage of time and the increase in the quantity of plutonium in existence will come pressure to eliminate the traditional checks the courts and legislatures place on the activities of the executive and to develop a powerful central authority better able to enforce strict safeguards." He avers that "once a quantity of plutonium had been stolen, the case for literally turning the country upside down to get it back would be overwhelming."[31] Ayres anticipates and worries about the kinds of thinking that, I have argued, characterize inherently political technologies. It is still true that, in a world in which human beings make and maintain artificial systems, nothing is "required" in an absolute sense. Nevertheless, once a course of action is underway, once artifacts like nuclear power plants have been built and put in operation, the kinds of reasoning that justify the adaptation of social life to technical requirements pop up as spontaneously as flowers in the spring. In Ayres's words, "Once recycling begins and the risks of plutonium theft become real rather than hypothetical, the case for governmental infringement of protected rights will seem compelling."[28] After a certain point, those who cannot accept the hard requirements and imperatives will be dismissed as dreamers and fools.

* * *

The two varieties of interpretation I have outlined indicate how artifacts can have political qualities. In the first instance we noticed ways in which specific features in the design or arrangement of a device or system could provide a convenient means of establishing patterns of power and authority in a given setting. Technologies of this kind have a range of flexibility in the dimensions of their material form. It is precisely because they are flexible that their consequences for society must be understood with reference to the social actors able to influence which designs and arrangements are chosen. In the second instance we examined ways in which the intractable properties of certain kinds of technology are strongly, perhaps unavoidably, linked to particular institutionalized patterns of power and authority. Here, the initial choice about whether or not to adopt something is decisive in regard to its consequences. There are no alternative physical designs or arrangements that would make a significant difference; there are, furthermore, no genuine possibilities for creative intervention by different social systems—capitalist or socialist—that could change the intractability of the entity or significantly alter the quality of its political effects.

To know which variety of interpretation is applicable in a given case is often what is at stake in disputes, some of them passionate ones, about the meaning of technology for how we live. I have argued a "both/and" position here, for it

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seems to me that both kinds of understanding are applicable in different circumstances. Indeed, it can happen that within a particular complex of technology—a system of communication or transportation, for example—some aspects may be flexible in their possibilities for society, while other aspects may be (for better or worse) completely intractable. The two varieties of interpretation I have examined here can overlap and intersect at many points.

These are, of course, issues on which people can disagree. Thus, some proponents of energy from renewable resources now believe they have at last discovered a set of intrinsically democratic, egalitarian, communitarian technologies. In my best estimation, however, the social consequences of building renewable energy systems will surely depend on the specific configurations of both hardware and the social institutions created to bring that energy to us. It may be that we will find ways to turn this silk purse into a sow's ear. By comparison, advocates of the further development of nuclear power seem to believe that they are working on a rather flexible technology whose adverse social effects can be fixed by changing the design parameters of reactors and nuclear waste disposal systems. For reasons indicated above, I believe them to be dead wrong in that faith. Yes, we may be able to manage some of the "risks" to public health and safety that nuclear power brings. But as society adapts to the more dangerous and apparently indelible features of nuclear power, what will be the long-range toll in human freedom?

My belief that we ought to attend more closely to technical objects themselves is not to say that we can ignore the contexts in which those objects are situated. A ship at sea may well require, as Plato and Engels insisted, a single captain and obedient crew. But a ship out of service, parked at the dock, needs only a caretaker. To understand which technologies and which contexts are important to us, and why, is an enterprise that must involve both the study of specific technical systems and their history as well as a thorough grasp of the concepts and controversies of political theory. In our times people are often willing to make drastic changes in the way they live to accord with technological innovation at the same time they would resist similar kinds of changes justified on political grounds. If for no other reason than that, it is important for us to achieve a clearer view of these matters than has been our habit so far.

References

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[2]Lewis Mumford, "Authoritarian and Democratic Technics," *Technology and Culture,* 5 (1964): 1-8.

[3]Denis Hayes, *Rays of Hope: The Transition to a Post-Petroleum World* (New York: W. W. Norton, 1977), pp. 71, 159.

[4]David Lilienthal, *T.V.A.: Democracy on the March* (New York: Harper and Brothers, 1944), pp. 72-83.

[5]Daniel J. Boorstin, *The Republic of Technology* (New York: Harper & Row, 1978), p. 7.

[6]Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought* (Cambridge, Mass.: M.I.T. Press, 1977).

[7]The meaning of "technology" I employ in this essay does not encompass some of the broader definitions of that concept found in contemporary literature, for example, the notion of "technique"

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in the writings of Jacques Ellul. My purposes here are more limited. For a discussion of the difficulties that arise in attempts to define "technology," see Ref. 6, pp. 8-12.

[8]Robert A. Caro, *The Power Broker: Robert Moses and the Fall of New York* (New York: Random House, 1974), pp. 318, 481, 514, 546, 951-958.

[9]*Ibid.*, p. 952.

[10]Robert Ozanne, *A Century of Labor-Management Relations at McCormick and International Harvester* (Madison, Wis.: University of Wisconsin Press, 1967), p. 20.

[11]The early history of the tomato harvester is told in Wayne D. Rasmussen, "Advances in American Agriculture: The Mechanical Tomato Harvester as a Case Study," *Technology and Culture*, 9 (1968): 531-543.

[12]Andrew Schmitz and David Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," *American Journal of Agricultural Economics*, 52 (1970): 569-577.

[13]William H. Friedland and Amy Barton, "Tomato Technology," *Society*, 13:6 (September/October 1976). See also William H. Friedland, *Social Sleepwalkers: Scientific and Technological Research in California Agriculture*, University of California, Davis, Department of Applied Behavioral Sciences, Research Monograph No. 13, 1974.

[14]*University of California Clip Sheet*, 54:36, May 1, 1979.

[15]Friedland and Barton, "Tomato Technology."

[16]A history and critical analysis of agricultural research in the land-grant colleges is given in James Hightower, *Hard Tomatoes, Hard Times* (Cambridge, Mass.: Schenkman, 1978).

[17]David Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools," in *Case Studies in the Labor Process* (New York: Monthly Review Press, forthcoming).

[18]Friedrich Engels, "On Authority" in *The Marx-Engels Reader*, 2nd ed., Robert Tucker (ed.) (New York: W. W. Norton, 1978), p. 731.

[19]*Ibid.*

[20]*Ibid.*, pp. 732, 731.

[21]Karl Marx, *Capital*, vol. 1, 3rd ed., Samuel Moore and Edward Aveling (trans.) (New York: The Modern Library, 1906), p. 530.

[22]Jerry Mander, *Four Arguments for the Elimination of Television* (New York: William Morrow, 1978), p. 44.

[23]See, for example, Robert Argue, Barbara Emanuel, and Stephen Graham, *The Sun Builders: A People's Guide to Solar, Wind and Wood Energy in Canada* (Toronto: Renewable Energy in Canada, 1978). "We think decentralization is an implicit component of renewable energy; this implies the decentralization of energy systems, communities and of power. Renewable energy doesn't require mammoth generation sources of disruptive transmission corridors. Our cities and towns, which have been dependent on centralized energy supplies, may be able to achieve some degree of autonomy, thereby controlling and administering their own energy needs" (p. 16).

[24]Alfred D. Chandler, Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass.: Belknap, Harvard University Press, 1977), p. 244.

[25]*Ibid.*

[26]*Ibid.*, p. 500.

[27]Leonard Silk and David Vogel, *Ethics and Profits: The Crisis of Confidence in American Business* (New York: Simon and Schuster, 1976), p. 191.

[28]Russel W. Ayres, "Policing Plutonium: The Civil Liberties Fallout," *Harvard Civil Rights-Civil Liberties Law Review*, 10 (1975):443, 413-4, 374.

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DANIEL T. SPRENG AND ALVIN M. WEINBERG

Time and Decentralization

MOST OF US, AT LEAST IN WESTERN CULTURES, value time more than we value energy. Thus our drive to use more energy is largely motivated by our desire to use less time. We see this trade-off between time and energy in hundreds of everyday ways. Airplanes replaced railroads because they are much faster, even though they use more energy. At 55 miles per hour we use less gasoline per mile, but we save this energy at the expense of time.

The duality between time and energy is also based in irreversible thermodynamics, as stressed by W. van Gool.[1] Suppose we are firing bricks in a kiln. For maximum thermodynamic efficiency, the temperature difference between the bricks and the heat source would vanish—but the heat would then flow infinitely slowly, and the output of bricks per day would be zero. More generally, for any processes that involve flow of heat, rate of production goes up as temperature gradients become steeper. But as temperature gradients become steeper, the process becomes more and more irreversible, that is, the process uses more energy. This is one scientific basis for the aphorism "Haste makes waste."

One way of avoiding steep temperature gradients, and therefore improving efficiency, is to make the heat exchange surfaces very large. In principle, one could then achieve very high heat-transfer rates with very small temperature differences, and approach theoretical energy efficiencies even when the production rates are high. But the apparatus becomes very expensive, and in the limit of maximum theoretical efficiency, it becomes infinitely large and infinitely costly. Moreover, though one saves process energy (the minimum process energy being the difference between the Gibbs Free Energy of the final product and the raw materials), one pays in embodied energy of the apparatus. In the limit, the embodied energy becomes infinite when the apparatus becomes infinitely large. Again, "haste makes waste."

One can get around "haste makes waste" through ingenuity: improvement in technology can reduce inefficiencies. For example, the efficiencies of aircraft gas turbines have improved enormously since Whittle's first jet engine, largely as a result of the development of metals that can withstand much higher temperatures. In short, ingenuity (including good organization), or more generally, "information," as well as time, can substitute for energy.

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One can visualize time, energy, and information as forming a triad: each, to some extent, is substitutable for the other.[2] By going slower (and spending time) we can save energy; if we have more information, say, of the future, or are more technologically sophisticated, we can better optimize the design of our energy system; or if we are prepared to waste energy, we can often save time, or make up for lack of information (for example, by grossly overdesigning a reactor pressure vessel, and thus increasing its embodied energy, to make up for our inability to calculate in detail its thermomechanical behavior under radiation and temperature stresses).

These ideas are summarized in a three-component phase diagram (Figure 1) in which the state of the system is characterized by three parameters: time, energy, and information. In this diagram each point inside the triangle represents a possible mix of energy, information, and time necessary to accomplish a certain task. When much available energy is employed, the point will be indicated at the upper left side of the triangle; if less energy is required, the point moves toward the opposite corner E = 0. Two methods to accomplish a job with the same requirement of available energy will be represented by points lying on a line parallel to the side of maximum available energy use. Near the corners of the triangle are the situations of the starving philosopher (near E = 0), who employs much information and time to accomplish his task; of a primitive man, perhaps in a slash-and-burn society (near I = 0), who, because of little information, requires much time and energy (a large area of forest) to meet his needs; and of the "industrial man" (near t = 0), who, with much energy and information, accomplishes things very quickly.

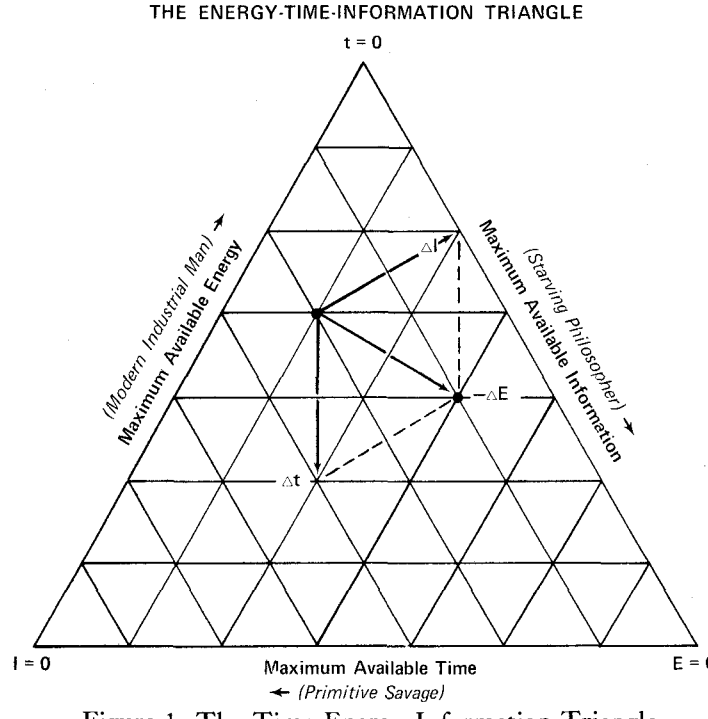

Figure 1. The Time-Energy-Information Triangle

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The diagram underlines the fact that energy conservation measures, $-\Delta E$, can be simultaneously the substitution of time, Δt, and the substitution of information, ΔI, for energy. For instance, increasing the efficiency by slowing down heat flows (i.e., by reducing the output rate or increasing the size of equipment) has to be done with expertise and know-how. Or, the educational process to disseminate energy conservation know-how requires time and patience.

This philosophic, perhaps poetic, analysis is relevant to the issue of centralization and decentralization of energy systems. If one were to ask what drove our energy system toward centralization, we would insist that our traditional high valuation of time was a key element. The centralized system provided energy services more reliably (and therefore with less expenditure of the consumer's time or demand on his ingenuity) and at less cost than did the decentralized system. This surely was an incentive for rural electrification, although one might argue that, without government subsidy, the cost to the consumer for the centralized electrical system might have been much higher than it was. Thus a rational choice between centralized and decentralized systems must take into account the freedom to allocate time, that is, the convenience afforded by one or the other system. It is puzzling that so little of the debate over centralized and decentralized energy systems (for example, as evidenced in the writings of A. Lovins,[3] B. Commoner,[4] or even the Harvard Energy Project[5]) has been devoted to the cost of maintaining an acceptable level of convenience. It is this element that we propose to inject into the debate.

Stochastic and Nonstochastic Systems

Every energy system is stochastic in the sense that, regardless of the primary fuel, equipment breaks down unpredictably. Energy systems fueled by storable fuels—coal, oil, uranium, or biomass—however, are not inherently stochastic; whereas systems that depend on solar flux sources—wind, direct solar, waves—are inherently stochastic. Basically, a nonstochastic energy source places fewer limits on our freedom to allocate time than does a stochastic one.

Intermittency, whether stochastic or predictable (as in the diurnal cycle), can be dealt with in two ways. The simplest is to live with it. Throughout man's history he has adjusted to the sun's intermittency; for example, artificial illumination was not very practical until the gas mantle and electricity were introduced. Even now some industries are conducted stochastically: construction usually stops when the weather is bad, even though this adds to the cost of the job.

But, driven by our desire to control time, we generally are willing to pay extra to avoid intermittency. We pay with redundancy, as when we back up a central electric generator by a spinning reserve; or when we back a solar heating system with an electric or gas grid, or with storage, say, with a bed of hot rocks. A sufficiently redundant backup system could, in principle, take over the entire load; for example, a central gas backup for a solar system could handle the whole load if one always has gas available. Whether to use the backup fuel rather than the on-site storage system depends, of course, on its cost and availability.[6] On the other hand, the capacity of a local storage system (like a bed of

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rocks) is both finite and to some extent uncertain, since it itself is filled by the stochastic energy source. Though in principle it could carry the full load under every circumstance, to do so might require an unpractically large storage.

Even in decentralized systems where the fuel is nonstochastic, there is a trade-off between cost and reliability: to make any system more reliable entails extra cost. Moreover, as W. Gilmer and R. Meunier of the Institute for Energy Analysis have pointed out, reliability can be enhanced through better organization of the service infrastructure—that is, a more effective mobilization of information—as well as by improved technical means. When the refrigerator goes out, one calls a service man. The length of interruption depends on how convenient and how competent the service is. Thus one can suppose decentralized systems to be characterized by the elaborateness of the institutional structures that are likely to be required to achieve a given degree of reliability.

Perhaps a specific example will make this point clearer. Consider a group of two dozen houses, condominium style, that supply their own heat and electricity from a gas-fired Stirling engine that exhausts to a hot-water heater. The energy system would require the regular services of a maintenance man; or, alternatively, the individual families could take turns maintaining the power plant. In either case, some degree of institutional stability and organization (perhaps a power subcommittee of the condominium board of directors) would be required to ensure reliable operation of the power system. The amount of organization required of the energy users to maintain reliable energy supply is rather greater than if the users were simply hooked into the local utility.

We have here a continuum. At one end is the completely centralized system based on storable fuel like coal. It involves a very few very large units and rather automatically possesses the infrastructure necessary to maintain it. At the other extreme are the completely decentralized, either stochastic or nonstochastic, systems. They involve innumerable small units and correspondingly complex service infrastructure—unless, of course, we are prepared to forego the reliability supplied by this elaborate structure and spend our own time and knowledge in tinkering with our private energy system.

The creation of an infrastructure that would be adequate to ensure high reliability in a dispersed system itself may be complicated. In this respect, the centralized system, involving fewer participants and fewer individual decisions, is more easily achieved than is the decentralized, at least if the same degree of reliability is demanded.

Many years ago, one of us, in introducing the idea of Technological Fixes, asked, "Can Technology Replace Social Engineering?"[7] The main point was that technological fixes require far fewer individual decisions or changes in individual behavior than do social fixes. For example, an intrinsically safe car is an easier means to reducing traffic fatalities than is an educational program aimed at teaching people to drive without drinking.

It is striking that in the central-decentral debate one finds this theme replayed. Decentralized energy systems such as individual solar collectors require much more participation from the energy user than does the centralized energy system. The latter, the epitome of large technology, avoids the necessity of teaching each householder how to be a power engineer. It demands less ingenuity and time of the consumer than does the dispersed system.

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One must not downgrade the role of the technology in easing this burden of maintenance on the individual who uses a dispersed energy system. One has every right to expect that, as technology improves, the demands on the individual's time and ingenuity will diminish. Yet neither can one ignore these demands. Our automobile is as thoroughly engineered a prime mover as there is, yet most people spend extraordinary amounts of time servicing (or arranging for servicing) their automobile. In speaking to people who have lived on farms before rural electrification, one is impressed with the effort they expended, not to say responsibility they bore, in keeping what primary energy system they had working. We are eons beyond the old Delco-wind-electric system. Yet, before we cast aside centralized energy systems, let us have a clear idea of the technical and institutional improvements that are required by a *reliable* decentralized system, especially one that is inherently stochastic.

The Costs of Intermittency

To avoid intermittency, or, more generally, to convert a stochastic energy system into a reliable one, will itself entail costs—in capital (for backup or storage), in establishment of an adequate service infrastructure, and possibly in time and convenience of the individual end user of energy. Here we encounter a difficulty: what this cost is likely to be will depend strongly on the degree to which the entire system is decentralized. If the decentralized system, whether stochastic or nonstochastic, is a small appendage on a powerful centralized system, the cost of intermittency and backup are relatively small, since the central system already has the reserve capacity to back up the decentralized system. As the decentralized system grows, relative to the centralized, it requires more and more reserve from the centralized system. This could become very costly, especially if the decentralized system is stochastic, for when, as happens, entire areas are covered by clouds, the central system would have to carry the entire load. Moreover, the load factor on this centralized backup would be very small and the prorated capital costs would be correspondingly large. If the decentralized system stands by itself, the costs of converting it into a reliable system obviously can be very large if one's demand for reliability is sufficiently great.

There is a trade-off between degree of decentralization and reliability (or, in our language, freedom to allocate one's time). As the system becomes more and more decentralized—in the limit, a stand-alone, individual household total energy system completely severed from the centralized backup—it becomes more stochastic, that is, less reliable. Indeed, as one contemplates the more extreme, perhaps idyllic, dreams of a future that would eventually eliminate the centralized backup, one wonders whether those who would live in this dream world are aware of the reallocation of time such energy systems would entail.

Qualitative statements of this sort are hardly useful for deciding what degree of decentralization we desire. Unfortunately, we know of no study that has explored this question fully: If we wish to achieve a certain degree of reliability from an inherently stochastic energy source, how much does it cost when the stochastic energy system constitutes a certain fraction of the backup central system? In particular, what is the cost when this fraction approaches unity, that

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is, there is *no* central backup, as seems to be implied in some all-solar futures visualized by the more extreme energy revolutionaries. This, to be sure, is a limiting case, yet considering the strong philosophic appeal of decentralized systems and the current mood of rejection of central systems, it is important to the energy debate that we have a clearer idea of what we may have to pay if we reject central energy systems.

Time and the Great Debate

The centralization/decentralization controversy goes far beyond the issue of energy: it is a recurring, even unending, theme in political philosophy. Though we have not encountered an explicit allusion to the role of time in this much broader and general debate, we would venture that this role is fundamental. Centralization of society's functions goes along with specialization. From the primitive who does everything he needs for his sustenance, to the modern city dweller who works at a single job and buys all of his logistic support, there is an unending drive toward centralization of function and toward specialization. This trend was propelled by the increase in efficiency inherent in specialization; or, putting it another way, by the increased freedom to allocate time that the specialized society provided its members.

Is human well-being better served in the centralized or in the decentralized society? We seem to be at a turning point in our attitudes: many are disaffected by the anomie, even the inefficiencies, in *over*centralization, whether of energy systems, corporations, or government. To be sure, the trend toward centralization, driven by the desire for efficiency, has always been impeded by the conflicting desire to be in charge of one's own destiny. But before we embrace the decentralized society, let us not lose sight of the ultimate advantage of centralization: the freedom it gives in allocating time. It is not self-evident that people, by and large, wish to be bothered by what they perceive as distractions from their own pursit of satisfaction, or for that matter, that the uniquely noble way to spend our lives is through intimate involvement with government, not to say with our personal Stirling engine or solar collectors. Indeed, as Robert A. Dahl says, "To be interested in politics . . . need not compete with one's primary activities. By contrast, active political participation frequently removes one from the arena of primary activities. Since the primary activities are voracious in their demands for time, political activity must enter into competition with them. For most people it is evidently a weak competitor."[8] Apparently most people would, if given the choice, rather perfect their backhands or their piano-playing than actively confront the intricacies of public policy or recalcitrant prime movers.

Who is to say which is the more fulfilling life? The issues go to the heart of the question "How shall we live?" The answers can hardly be given once and for all. The debate over centralization and decentralization is destined to go on as long as we aspire to the good life. The compromise we achieve at any time is almost surely temporary, to be overturned as each new generation recognizes the deficiencies in its elders' choice.

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REFERENCES

[1]W. van Gool, "Constraints on Energy Conservation," *Physics Today* 32 (3) (March 1979).

[2]Daniel T. Spreng, "On Time, Information, and Energy Conservation," ORAU/IEA-78-22(R), Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee, December 1978.

[3]Amory B. Lovins, "Scale, Centralization and Electrification in Energy Systems," in *Future Strategies for Energy Development, A Question of Scale*, ORAU-130, Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1977.

[4]Barry Commoner, *The Politics of Energy* (New York: Alfred A. Knopf, 1979).

[5]Robert Stobaugh and Daniel Yergin in *Energy Future, Report of the Energy Project at the Harvard Business School* (New York: Random House, 1979).

[6]J. G. Asbury and R. O. Mueller, "Solar Energy and Electric Utilities: Should They be Interfaced?" *Science* 195 (4277) (February 4, 1977), in which the authors argue that a solar heating system with storage backed up by an electric grid that delivers off-peak power is cheapest if the solar heat is eliminated.

[7]Alvin M. Weinberg, "Can Technology Replace Social Engineering?" *The University of Chicago Magazine* 59 (October 9, 1966). Actually, the notion of the technological fix had been discussed in 1956 by Richard L. Meier in *Science and Economic Development: New Patterns of Living.*

[8]Robert A. Dahl, *Who Governs: Democracy and Power in an American City* (New Haven: Yale University Press, 1961).

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DEBORAH SHAPLEY

Arms Control as a Regulator of Military Technology

IN THE TWENTY YEARS since it was devised, arms control has enjoyed an increasingly central position in American foreign policy, yet today it is paradoxically in dispute. There is much journalistic speculation about its future, or lack of one, and there is also beginning a major academic reexamination. The stark reasons are that, in the intervening two decades, military costs have risen: U.S. outlays have more than doubled, and the Soviet Union's have increased still more.[1] The destructiveness of the two arsenals has increased: in 1960 both sides together had 6,500 nuclear weapons; by 1979 they had 14,200. The latest arms control treaty, SALT II, would hardly limit these weapons in the ordinary sense of the word. According to official figures, under the treaty both sides' total strategic warheads could rise to 22,500-24,400 by 1985.[2] Finally, the political climate has changed; as of this writing, passage of the treaty by the Senate is in doubt, despite the fact that three presidents have sought the accord over the last five years. Clearly, at many levels, some crisis of arms control is upon us.

This essay will discuss one aspect of the failure of arms control to meet its own goals, and why weapons systems seem to keep on accumulating, proliferating, and changing despite efforts to limit them. To put it in a way relevant to discussions of technology, it will ask why arms control has been such a poor regulator of military technology.

One answer is that arms control and strategic doctrine offer only crude descriptions of the underlying complexity of weapons and what they can do. In fact, however, existing systems constantly undergo incremental improvements: as marginal changes accumulate, a system can evolve capabilities beyond its original mission. Thus weapons defined as stabilizing can evolve into ones that threaten stability, and capabilities that are viewed as undesirable, once improved and modernized, can become highly desirable. Innovation, by the same token, does not take place in the brains of some high officials but in the course of improving existing systems: one more Air Force armed decoy missile can carry the seeds of a revolutionary new system. On the other hand, high-level policymakers and arms control negotiators are not familiar with the fine structure of weapons evolution. They deal with things they can manipulate—the words, concepts, and definitions used in formulating doctrine and arms control positions. But since technological evolution is constantly making these definitions obsolete, it is small wonder that policymakers can be surprised, like the oper-

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ators in the control room of a nuclear power plant in a recent accident, when, having pushed the button marked "Control," the machine goes on malfunctioning. To put the case glibly, the machine has been "mis-wired"; we have been manipulating the wrong paradigms.

The essay will conclude with a list of issues that need to be better understood if we are to get a new grip on the arms race and if the United States is to maintain a sound posture toward a technologically competitive Soviet Union in the 1980s. A key need is for a better understanding of the dynamics of military technology and its potential in the armed forces. For, in the strategic environment of the 1980s, when the Soviets will possess many of the advanced technologies in which the United States has for so long enjoyed a lead, it will be critical for the United States to be able to capitalize on its remaining technological strengths and to use to advantage the creativity of its military and civilian sectors. Moreover, better knowledge of the fine structure of both U.S. and Soviet weapons evolution could serve as a fertile ground for the generation of new arms control initiatives.

Because this issue of *Daedalus* is devoted to technology, something should be said at the outset comparing military technology and the study of it with other technologies discussed in this volume. Military technology is often left out of more general discussions of technology. Scholars, after all, study what they can see, and military technology is relatively invisible by comparison with, say, the introduction of birth control, the Green Revolution, advances in medicine, and other things that impact on the consumer. Weapons, by contrast, are developed necessarily in secret by a partly secret wing of the government; their operation and rationale, even their physical location, are known only to a small elite. Thus, although it consumes half the nations R&D resources, military technology remains very much like the elephant being discovered by blind men: we have felt the ears and the tail, but we still do not know the exact shape of the beast.

There are two other interesting facts about military technology that affect the way it can be studied. One is that, although the majority of technical advances are marginal and nearly invisible, our military institutions and their missions, indeed even our foreign policy, have been shaped by a single technology, the atomic bomb and its sequel, the hydrogen bomb. Perhaps the only civilian comparison is the computer, which has so affected the handling and use of data that it has changed entire institutions and even affected national policy. And if one of the goals of studying technology is to anticipate its impact, it is noteworthy that the people who tried to alert the world to the impact of nuclear weapons in the 1940s focused on the impact of atomic weapons on war, but said far less about the impact of atomic weapons on the peace: the fact that rival armed services would each claim a role in the prestigious business of fighting strategic nuclear war; the push to develop "small" tactical nuclear weapons; the impact on alliances; and the decision by the Soviet Union (apparently not made until the late 1950s) to develop a full-scale strategic arsenal of its own.[3]

A second interesting fact that affects the study of military technology is its bifocal or reflective character. Unlike birth control or the Green Revolution, which can be studied only in comparison with a negative—namely, circum-

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stances when these advances did not occur—the weapons arsenal of the United States cannot be studied without reference to that of the Soviet Union. And although the two nations' military needs, force structures, and technological styles are very different, and although they probably impact on each other less than is popularly believed, it is clear that neither would exist in its present form without the existence of the other in *its* present form. Add to this the fact that there is even less public information about Soviet than about U.S. weapons, and we have more reasons that the subject resists study.

But we must not be discouraged by these obstacles. Recent events make it painfully apparent that we really do not understand what makes military forces evolve and expand, and that we do not have an effective means of regulating or orchestrating them. More important, the subject entails crucial questions of public policy in the 1980s, and possibly even national survival. So we must begin with the tools we have, namely, the existing models of the arms race and concepts offered by strategic doctrine, and what we do know of the weapons systems themselves.

I

The academic ferment and general alarm about the growing arsenals of both sides in the late 1950s produced an action-reaction model of the arms race. As refined and articulated in the 1960s,[4] it said the arms race proceeds by decisions by the leaders of one side to deploy new systems in reaction to deployments ordered by leaders on the other side. Implicit in this view were the ideas that the decisions of leaders actually determined force structure and that leaders' orders were carried out by the military bureaucracy. It also followed that, if the leaders of one side so chose, they could decide *not* to step up the arms staircase and could even step down.[5] Finally, it implied that the leaders of each side reacted rationally to the behavior of the other side, providing U.S. policymakers with the convenient belief that, if they behaved in certain ways, they could expect the Soviet Union to respond predictably and rationally.

The action-reaction cycle and other models that emerged at the time, and formed the intellectual basis for the negotiating efforts of the 1960s and 1970s, continued the theme of conscious choice. In 1960 Russell and then Kahn offered the analogy of the United States and the Soviet Union playing "Chicken," a game in which two drivers race at each other at breakneck speed, and the first one to swerve aside earns that *macho* label.[6] The Kahn analogy implied that well-brought-up nice boys did not play "Chicken" but pursued more sensible games such as—to use another favorite arms race metaphor of rational, conscious choice—chess. In the mid-1970s Warnke wrote about the "two apes on a treadmill" notion, suggesting that a smarter ape would step off.[7]

Another underlying assumption was that U.S. leaders could trust that their military doctrine was meaningful, that is, that it reflected U.S. force capabilities. This belief in the congruity of doctrine and capabilities entailed a belief that the Soviet Union would respect our doctrine as though it were meaningful and real. This is not the place to discuss doctrine *per se*, but only to point out that arms control proposals necessarily had to rely on military doctrine, and thus had to assume its validity.

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II

But one of the reasons arms control has not fulfilled its goals may be that neither the action-reaction, conscious-choice model nor doctrine may describe how military forces evolve and what they can do. So the "machine" goes on functioning, while arms controllers have pushed the wrong button. It seems more plausible that the military forces of both sides are only occasionally shaped by policymakers exercising conscious choice, and that doctrine is formulated so rarely, and so cumbersomely, that in a period of rapidly evolving technology and, hence, changing capabilities, it can become outdated without the knowledge of policymakers at the top. Rather, the capabilities of weapons seem to be shaped by the enthusiasm of scientists for advertising the potential of their work, the interest of program managers and design bureaus in testing improvements, and the armed services' wish to have the most up-to-date versions of their systems. I call this process "technology creep"[8] to emphasize its gradual, inconspicuous, bureaucratic character.

Moreover, since these small changes are conditioned by prevailing circumstances, and over time do not always add up to a coherent development strategy or military doctrine, they can be seen as an example of the "tyranny of small decisions" outlined by A. Kahn.

I also distinguish technology creep from true innovations in military technology, which seem to be rare. Steinbruner and Carter[9] have described how technological decisions are shaped by the political demands of the military bureaucracy, and Morison[10] has written about how the military resists and even suppresses a superior technology if it threatens existing roles and missions. In fact, today, the only "new" strategic weapon, the cruise missile, was developed as such after congressional leaders intervened in the normal Air Force development process to force the weapon to be developed in an innovative, instead of an add-on, mode.[11] Further, because military technology is characterized by these occasional high-level interventions, which in effect recombine the genetic material of an evolving weapons system, I distinguish technology creep from the technological "imperative" and "evolutionary" ideas put forward by Brooks.[12] While the military seems to absorb readily things it perceives as improvements to existing systems, and while these improvements sometimes transform capabilities, another kind of transformation occurs when a system that normally would survive is cancelled or changed from on high. In nature, such outside interventions do not occur.

The vulnerability of U.S. land-based ICBMs to Soviet attack in the early 1980s, which is the centerpiece of the current U.S. public debate, was caused by the failure of both arms control and strategic doctrine to limn the process of technology creep. In this case, high-level leaders sometimes encouraged, and sometimes discouraged, but for the most part ignored, the gradual modernization of U.S. and Soviet ICBM forces, and as a result landed us in our present fix.

Since the mid-1960s, when Secretary of Defense Robert McNamara put forward the doctrine of mutual assured destruction, the United States has said it would not seek a first-strike capability against the Soviet Union. Since, two high-level decisions tried to insure that our technical capabilities matched this

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doctrine. In the late 1960s it was decided not to deploy more than 550 Minuteman IIIs—then the most advanced U.S. ICBM—because a larger number could be perceived by the Soviet Union as a first-strike force. So the balance of U.S. ICBMs to this day is made up of older, less accurate missiles, the Titans and Minuteman IIs, that cannot be sure of destroying Soviet silos but would be used for less localized retaliatory strikes. Doctrine was also reaffirmed in 1974 and 1975 when Congress cut back Navy work on high-precision stellar inertial guidance for the traditionally less accurate submarine launched ballistic missiles (SLBMs), lest the Soviets perceive the SLBMs as becoming a first-strike force. (It was never clear, however, that the military commanders had implemented fully McNamara's doctrine; throughout this period, portions of the retaliatory force were programmed to strike "hard" Soviet military targets.)

There are many reasons the United States held to this doctrine. Obviously, if it announced a first-strike policy, the Soviets would be tempted in a crisis to fire at our ICBMs first, and such a hair-trigger world should be avoided. A cultural reason is the memory of Pearl Harbor, and the notion that the United States would not inflict such a blow on another nation. (In Allison's account,[13] this was one reason President John Kennedy was reluctant to order air strikes against Cuba in 1962.) Whatever the reason, no first strike has remained U.S. doctrine.

Nonetheless, an accumulation of improvements to U.S. ICBMs is making them accurate enough to have the appearance of a first-strike capability. (First strike is defined here as the ability of one side's land-based ICBM forces to attack a high [90 percent] fraction of the other side's ICBM forces. The term has sometimes been used to mean a successful attack against the other side's land-based ICBM, submarine, and bomber forces.) This change is the result of many small changes, the main ones being improved rocket motors and solid propellants (enabling quick takeoff); knowledge of the earth's gravity and geodesy (better programming of the ballistic trajectory); precision instrumentation (less wear on mechanical parts); heatproof materials (less nose cone distortion during reentry); smaller warheads (allowing more warheads per missile, more room for instrumentation); and electronics (refined inertial sensing and course correction, and terminal guidance). The result has been ICBMs that are steadily more accurate. The early Titans had CEPs[14] of 3,000 feet; Minuteman II, deployed in the 1960s, had CEPs of 2,000 feet; and Minuteman III, deployed in the 1970s, had CEPs of 1,020 feet. After the latest improvement to Minuteman III—a programming change that cost only $4 million to install in all 550 missiles—the CEP was reduced to 600 feet. The MX missile could have a CEP of 300 feet, according to unclassified sources. Also, with the addition of MX, in the 1980s the United States will have enough high-accuracy warheads to appear to have a first-strike capability. We are thus acquiring a capability we do not seek.

In one way, technology creep has forced us belatedly to change our doctrine. In the early 1970s, after the United States had begun testing MIRV, the ability to have several warheads independently guided to different targets from a single "bus," Secretary of Defense James Schlesinger altered U.S. policy by announcing that the United States would consider a limited nuclear war, using the high-accuracy part of its ICBM force against certain Soviet military targets.[15] In part, this was a rationalization for capabilities already developed.

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Since then, both the MX and improvements in SLBM accuracy (including the Navy's continuing research and development on MARV) have been justified for this "counterforce" role. Policymakers have simply ignored the technological reality, namely, that the difference between a counterforce capability and a first-strike capability against the opponent's ICBM force is largely one of degree. Thus, while updated, doctrine remained out of step with the emerging technical reality.

But arms control seems only to deal with a technology by vaunting it or banning it, and the United States, by vaunting its MIRV technology during the SALT I negotiations, hastened the day when its own ICBM force would feel vulnerable to a Soviet first strike. For the Soviets have been going down a similar curve: an early Soviet ICBM, the SS-8, had a CEP of 6,000 feet;[16] the SS-9, deployed later, had a CEP of 3,000 feet, and so on. Soviet doctrine calls for denying the enemy his capability to attack the Soviet homeland—which in strategic nuclear war terms means being able to knock out the U.S. ICBM force at a blow. But the Soviets took this view even in the early 1960s, when their military forces were totally incapable of carrying out this policy. So, over the years, evolutionary improvements in missile accuracy have enabled the Soviet ICBM force to come into line with doctrine.

At the time the SALT I negotiations were drawing to a close, one of the ways in which the United States was superior to the Soviet Union was in its MIRV capability—a capability that grew quite naturally out of the incremental developments mentioned above. MIRV allows a single "bus" to steer many warheads to different targets, thus multiplying the destructive power of a given missile. The early U.S. MIRV work was justified on the grounds that it could penetrate a future Soviet ABM. By 1972 MIRV had become an example of U.S. military-technical superiority that could help sell SALT I to the Senate, so Kissinger decided not to try to include a MIRV ban in the SALT I accords. Why, after all, should the United States hobble itself?[17]

After SALT I was signed, the Soviets began testing MIRV, and in 1975 they deployed it on their SS-17 and SS-19. True to the pattern of technology creep, the previous disadvantage of their heavy missiles, their huge size, became an advantage with MIRV. U.S. officials say that the large nose cone of the SS-18 "heavy" missile could accommodate as many as forty MIRVed warheads, although they have been test-fired with fourteen. (The Minuteman III has three MIRVs; the MX will have ten.) Thus U.S. officials predict that, when the SS-18 is fully deployed in the 1980s, the Soviets will have a theoretical capability of destroying U.S. ICBMs on a first strike.

Finally, because of this threat, President Carter has pressed for development of both the MX and a $40 billion "racetrack" mobile basing scheme to protect the MX from attack. This interplay of the U.S. MIRV, SALT, Soviet capabilities, and expensive new systems for the United States illustrates how inadequate arms control has been in dealing with the real dynamics of the growth of military forces. Neither arms control policy, doctrine, nor political wisdom dictated it at the time, but, in retrospect, U.S. restraint of its own MIRV could have stopped or delayed this chain of events.

There are many other examples of technological evolution outwitting arms control, including several on the Soviet side. Soviet weapons procurement is

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much more evolutionary than that of the United States: the Soviets have several major design bureaus specializing in different kinds of systems; they continue working even after a new ICBM or airplane is deployed—therefore, they work on modifications to it that ultimately appear in the next missile or airplane. Alexander[18] has shown how several "new" Soviet weapons systems were the result of this bureaucratic-technological evolution. He writes of the Soviet system: "Incrementalism, maintained continuously and for a long time, can produce substantial change." The fact that changes in deployed weapons must be approved by so many layers in the hierarchy acts as a brake on innovation. For instance, the MIG-25 Foxbat aircraft, which was widely assumed in the United States to have been developed in response to the U.S. B-70 bomber, in fact was a conservative variant of the Y-166 prototype series that the Soviets had tested previously. Similarly, the T-62 tank, which, because it is a field-tested design retrofitted with modern weapons, is superior in some ways to its U.S. counterpart, derives from a design made by J. Walter Christie in the 1930s.[19] Holloway has noted that, alongside this conservative, evolutionary pattern, there has been a series of Soviet weapons, such as the Galosh ABM, the SS-6 ICBM, and Mya-4 (Bison) bomber, in which technology could not meet the politically dictated system requirements.[20]

Kriegel, although she has not addressed the Soviet weapons procurement process as such, has offered this definition of the Soviet technological style:

> The Soviet system then . . . need not value change or the capacity for change. Imagination, invention, the "new," the "never seen before" do not interest it. Let others make the expensive scientific or technological "firsts." If they prove usable, it is easy enough, and certainly cheaper, to send over an official, or secret team, to bring back the applicable formulae, plans, models or prototypes.[21]

According to this view, Soviet leaders do not react to U.S. weapons deployments by ordering up a unique response: instead, they imitate Western weapons that look "usable."

Both sides are experiencing other cases of technology creeping around the limits set by arms control and doctrine, which pose potentially serious problems for the 1980s. One is U.S. progress in antiballistic missile technology, which is already leading to pressures to deploy ABM in the 1980s to protect the U.S. ICBM force from Soviet attack.

The 1972 SALT I treaty is often described as the quintessence of arms control, for it not only prohibited the building of expensive new systems, but reaffirmed the no-first-strike doctrine. (By renouncing deployment of ABM shields, neither side can now protect itself from a retaliatory blow if it strikes first. Thus, a first strike must lead to mutual destruction and is therefore deterred.) But even this triumph of restraint had a technological rationale: in 1972 ABM looked impractical. It would have required many large, vulnerable radars; a giant central computer that would both be a target and might not work; and the notion of short-range Sprint nuclear missiles, rising up over U.S. cities to intercept Soviet ones coming in from the upper atmosphere, didn't seem workable.

Today, a decade after Congress nearly halted ABM because of these arguments, sensing and electronics advances have given birth to an array of terminal

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homing weapons. These were developed for conventional warfare and for antisatellite use, but some of the advances could be applied to ABM. There has been progress in making radars smaller and cheaper. When linked to their own small computers, the most difficult ABM problem of rapid multiple target location and simultaneous tracking could be performed by the radars. Some have suggested that the 1972 treaty be reopened to allow the United States to deploy ABM to protect a portion of its ICBM force. Others respond that doing so could lead to the death of the treaty and a new arms race in ABMs. Technical capability and arms control, which with respect to ABM have worked together in the past, may not do so in the future.[22]

Another arms control effort of the United States has been to demilitarize space, but this too is eroding under the pressure of technology creep. Since 1960 arms control has had an ally in the form of the reconnaissance satellite, which enabled both sides to monitor each others' deployments while avoiding the political problem of onsite inspection. For twenty years, reconnaissance has been an exclusively peaceful, stabilizing technology because it was imperfect: it could not see through cloud cover; it saw only isolated pictures as a result of routine passes over an area, and its product could be viewed by intelligence officials only weeks or days later. But with the growing modernization of these satellites, more of them have "stare" capabilities for continuous monitoring of large areas with high resolution; more of them relay their data to the ground in real time; and there is a growing potential to see through cloud cover. These capabilities will make reconnaissance satellites "stabilizing" and "destabilizing" at the same time: a satellite that could monitor troop movements in Eastern Europe could monitor a mutual balanced force reduction agreement, but it could also help the West fight another European war. Likewise, while the United States might desire high-resolution, all-weather monitoring of the ocean to keep track of the growing Soviet surface fleet, it could fear such a capability in the hands of the Soviets, who could look down at the stormy North Atlantic in wartime to see convoys headed for Europe.[23]

Increasingly as a response, both sides are developing antisatellite weapons with which to destroy each others' satellites at the outbreak of a war, hardening their own satellites against attack, and proliferating satellites into redundant systems that could survive attrition from the hostile activities of the other side. It seems that no system is immune from the unpredictable effects of technology creep: even the peaceful activity of reconnaissance, as it modernizes, is generating a new arms race in space.

III

The foregoing has stressed technology as the foil of arms control and military doctrine. But technology is only one strand in the knot that shapes military forces: political, bureaucratic, institutional, and cultural strands clearly are at work too. A thorough analysis of what determines each side's forces would have to describe these, and some scholars, notably Allison and Steinbruner, have been doing this, thus chipping away at the paradigms of the early 1960s. (Allison's study of the Cuban missile crisis showed that military bureaucracies do not always do what the leaders think they are doing: (1) President Kennedy

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twice ordered the removal of the Jupiter missiles from Turkey without the order being carried out, and (2) while the president was carefully orchestrating what he thought was the first encounter between Soviet and American warships during the crisis, the U.S. submarine commanders had already forced Soviet submarines in the Atlantic to surface, as part of standard operating procedure in a period of alert.)[24] Thus the significance of the previous discussion of technology creep is not to propose it as exhaustive model, but only to show that in technology, which determines force capabilities, the gulf between the views of leaders exercising conscious choice and the underlying reality can be very great indeed.

Moreover, analogies are by nature simplistic, and there is little to be gained by flailing away at them for long, except to prove Lord Keynes's point that most practical men are the slaves of some defunct theorist of their youth. The really interesting question is not that our ideas are out of date, but what ideas shall replace them. That is, knowing that indigenous forces, rather than action-reaction or conscious choice, shape the arsenals of the United States and the Soviet Union, how can they be controlled or at least shaped in a rational, stabilizing way in the 1980s?

The foregoing does explain, however, why two of Schelling's three goals for arms control have not been met.[25] Since arms control accords can limit only large, countable weapons that can be traced by satellite, it is obvious that they cannot directly limit the bureaucratic-technological activities that make up each side's military establishment. These can proceed unchecked, raising military budgets and, hence, defying Schelling's first goal of reducing the costs of preparing for war.

Schelling's second goal, to reduce the destructiveness of war should it occur, has not been fulfilled because nuclear weapons are too small to be directly verifiable, and, hence, to be directly limited by treaty. Although perhaps inhibited by the 1963 test ban treaty, nuclear weapons have been allowed a constant process of modernization, and, as the figures at the beginning of this article show, their numbers have increased, and may increase dramatically in the next few years due to MIRV.

But Schelling's third goal, that arms control should reduce the risks of war, remains as valid as ever. Taken alone it is but the tenet of diplomacy that two nations who seek to avoid conflict sit down to negotiate a stable arrangement. The arms control treaties thus far seem to have enhanced this goal: war has not broken out and the strategic balance for most of two decades has been more or less stable.

But negotiated agreements are limited in what they can do. Just as no nation would rely on its treaties alone to shape its foreign policy, so we should refrain from relying on arms control accords to determine our military posture and activities. In fact, the foregoing suggests several things that need more attention in the 1980s.

1. The question of our response to the projected Soviet first-strike capability needs clear definition and debate, as do the president's recommended solutions to proceed with the MX missile and to deploy it in a "racetrack" mode. The doctrinal implications of a U.S. first-strike capability, both through MX and through general modernization of the Minuteman force, must be squarely

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faced. With MX, the U.S. seems to be deciding to acquire a capability because the Soviets are going to have it, not because it is considered an inherently wise idea.[26] Similarly, the proposed "racetrack" plan, designed to preserve the deterrent, retaliatory feature of U.S. land-based ICBMs, may promote instability: should the Soviet Union follow its historic pattern and copy the U.S. mobile system with one of its own, the system could well be unverifiable and allow a buildup of enough "extra" ICBMs to make possible a successful Soviet first strike against even the U.S. mobile-based MX. Thus neither MX alone, nor MX with a mobile basing mode, seems to offer the stability the United States says it seeks. An alternative that has been studied would be to allow only limited modernization of the ICBM force, with or without MX, and to enhance the "dyad" of U.S. strategic submarines and bombers. This would be difficult because it would involve reining in the bureaucratic and technological pressures that are building for full deployment of MX and for a mobile basing system. But it would have the advantage of offering stability in the near term as well as in the late 1980s if the Soviets chose to copy us and put a greater fraction of their strategic weapons aboard submarines and bombers. This approach would not have the conceptual weakness of past U.S. military and strategic decisions, namely, that the arms escalator can be halted, but at the next step rather than this one.

2. For the longer term, we need more precise understanding of the unilateral indigenous forces at work that determine the size and character of each side's military forces. This knowledge is scattered at present among the war colleges, in some universities, in the Central Intelligence Agency, and in the Directorate of Defense Research and Engineering of the Department of Defense. Precise questions need to be formulated and answered regarding the respective roles of culture, institutions, technology, and even historical accident upon each side's forces. An intriguing possibility raised by Wright[27] is whether the main brake on the expansion of U.S. strategic forces in the 1960s was the Apollo program, which absorbed the energy and creativity of the U.S. scientific and industrial sector that normally builds advanced military systems. On the Soviet side, clearly the largest brake on Soviet military programs, historically, has been its poor economy. This raises the question of how the economic troubles being forecast for the Soviet Union in the 1980s will affect the military strength projected for her for the same period.

Another intriguing set of questions is whether the U.S. military is shaped by a cultural bias for "imagination, invention, the 'new,' the 'never seen before' " and expensive technological "firsts." Much U.S. weapons procurement suggests a preference for complexity over simplicity, for advanced technology over previously fielded components, and the like. A discussion along these lines has already started about U.S. shipbuilding and whether the Navy's preference for building a smaller number of very advanced, relatively expensive platforms is the correct strategy, in view of the Soviet's equally pronounced penchant (which may also be culturally influenced) for building a larger number of less capable ships. (It should be noted that, at present, the Soviet builds as many submarines per year as the entire number of ships built annually for the U.S. Navy.) In aircraft, the United States has tried to roll back the level of advanced

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technology packed into new models and to produce simpler, cheaper planes with mixed success.[28]

3. Identification of the cultural and institutional preferences that shape U.S. forces will provide a tool for uncovering our weaknesses and those of the Soviet Union. To continue the example: if the United States military has a penchant for sophisticated hardware, it is likely to neglect, on a systematic basis, software problems such as command and control and other issues, such as the maintenance and reliability of deployed equipment or force readiness. Even Defense Secretary Harold Brown, who has sought to improve the readiness of U.S. forces in Europe, has complained of the difficulty of getting Congress to focus on the unglamorous items involved, such as bullets, prepositioning of supplies, and cargo aircraft. Congress prefers to discuss new hardware items, such as a new nuclear-powered aircraft carrier.

Another weakness could lie in the issue of whether the advanced technology the U.S. military relies on is suffering from the same problems of declining productivity and innovativeness that is plaguing advanced technology in the civilian sphere. For instance, is U.S. military equipment depending more and more on components made in West Germany and Japan? Wohlstetter[29] has noted that part of U.S. military doctrine has been the belief that the superior and unique U.S. industrial capacity would be the sustaining, decisive factor in any future war. But in the world of the 1980s, which will be a more economically and technologically leveled world than what we have known before, this belief may need to be revised. (A further complication is whether a United States that is dependent on Middle Eastern oil could play the sustaining, life-giving role envisioned for it in a protracted war, but this is only partly a technological question.)

4. This improved understanding could greatly help the United States cope with a world of U.S.-Soviet parity. According to present forecasts, by the mid-1980s the Soviet Union will have eliminated the lag in strategic offensive nuclear weapons that has characterized the entire postwar period. And given that the conventional military balance in Europe tends to favor the Soviets, and given the growth of the Soviet Navy, it is certain that the overall balance in the 1980s will be different from anything the United States has known in the nuclear age. It is relevant that previous "scares" that the United States had a true military rival, such as after Sputnik, have provoked domestic political trauma in the United States. It is also relevant that U.S. foreign policy has adopted the aims and goals of the arms control movement of the early 1960s during a period of unquestioned U.S. military superiority. Arms control may be far less popular in a world of parity.

Parity will also draw public attention to marginal deployments on either side and generate pressure to imitate Soviet technical strategies, even if they seem unwise to us. This seems to be happening with MX; it has already happened with directed energy weapons. Over the years U.S. scientific opinion thought a major U.S. program would be less than useful; but news reports of a big Soviet energy beam project generated pressure for the United States to upgrade its efforts. Our situation may come to resemble a sailboat race, where a ship doing well on its course will veer to follow its opponent whenever the opponent takes

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off on a course change. The first boat must be well ahead of the opponent for it not to follow the opponent's course change. It will take self-knowledge, maturity, and confidence not to be pressured into too much imitation of our technologically less adept rival.

We need, then, more understanding and study of (1) Soviet weapons developments and their implications; (2) a review of the possible U.S. technological responses (a survey that one official now says is performed "in the head of the Director of Defense Research and Engineering"); and (3) careful orchestration of an optimal response by the U.S. armed services. In the past the U.S. military lead has allowed technology creep to proceed largely by serendipity and chance. A few suppressed innovations mattered little because of this lead. But in a world of U.S. parity with a more technically sophisticated Soviet rival, the United States will have to husband its technological resources and make the most of its advantages to turn our now malfunctioning mad machine into a well-tuned one. As for arms control, while our efforts may be less ambitious than they have been in the past, our hopes for it diminished, and the accords themselves more limited in scope,[30] if they are built on a better understanding of both Soviet and American technology, they nonetheless will be sound.

References

[1]U.S. outlays are from *National Defense Budget Estimates for FY 1979*, Office of Assistant Secretary of Defense (Comptroller), Chart 1-6, p. 9 ("national defense" outlays in current dollars). Soviet outlays from *Allocation of Resources in the Soviet Union and China—1977*. Hearings before the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee, U.S. Senate, 95th Congress, 1st Session; Part 3, p. 23.

[2]Weapons estimates for 1960 from Center for Defense Information, Washington, D.C. Weapons estimates for 1979 from Department of Defense *Annual Report Fiscal Year 1980, Harold Brown, Secretary of Defense*, p. 71, Table 5-2. Projected SALT II weapons increases from the Department of Defense, Office of Public Affairs. Figures do not include stockpiles.

[3]See, for example, Alice Kimball Smith, *Peril and a Hope: The Scientists' Movement in America, 1945-47* (Chicago: University of Chicago Press, 1965).

[4]The early arms control writing entailed logical modeling of the behavior of one side in reaction to the other. G.W. Rathjens later put forward an "action-reaction" model as such, but recently criticized this view. See Rathjens, private communication, 1966; Kistiakowsky and Rathjens, "The Limitation of Strategic Arms," *Scientific American*, 1970; Rathjens, *The Future of the Strategic Arms Race: Options for the 1970s* (New York: Carnegie Endowment for International Peace, 1969); and W. Slocombe, *Controlling Strategic Nuclear Weapons, Headline Series*, The Foreign Policy Association, June 1975, pp. 52-53.

[5]Thomas C. Schelling draws attention to this up-down belief in "Reciprocal Measures for Arms Stabilization," *Daedalus*, Fall 1960, 893.

[6]Bertrand Russell, *Common Sense and Nuclear Warfare* (New York: Simon and Schuster, 1959), and Herman Kahn, "The Arms Race and Some of Its Hazards," *Daedalus*, Fall 1960, 756-57.

[7]Paul C. Warnke, "Two Apes on a Treadmill," in *Foreign Policy*, 18 (Spring 1975): 12-29, esp. 29.

[8]Deborah Shapley, "Technology Creep and the Arms Race: ICBM Problem a Sleeper," *Science*, 22 (September 1978): 1102-05; Shapley, "Technology Creep and the Arms Race: A World of Absolute Accuracy," *Science*, 29 (September 1978): 1192-96; and Shapley, "Technology Creep and the Arms Race: Two Future Arms Control Problems," *Science*, 20 (October 1978): 289-91.

[9]John Steinbruner and Barry Carter, "Organizational and Political Dimensions of the Strategic Posture: The Problems of Reform," *Daedalus*, Summer 1975, 131-54.

[10]Elting Morison, *Men, Machines and Modern Times* (Cambridge, Mass.: M.I.T. Press, 1966).

[11]Deborah Shapley, "The B-1 and the Cruise Missile: To Have and Have Not," *Science*, 193 (4250) (July 1976): 303-5, and Shapley, "Cruise Missiles: Air Force, Navy Weapon Poses New Arms Issues," *Science*, 187 (4175) (February 1975): 416-18

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[12]See Feld, Greenwood, Rathjens, Weinberg (eds.), *Impact of New Technologies on the Arms Race* (Cambridge, Mass.: M.I.T. Press, 1971), p. 320; and Harvey Brooks, "The Military Innovation System and the Qualitative Arms Race," *Daedalus,* Summer 1975, 75-97, esp. 90-93.

[13]Graham T. Allison, *The Essence of Decision* (Boston: Little, Brown, 1971).

[14]Herbert F. York, *Race to Oblivion* (New York: Simon & Schuster, 1971).

[15]Lynn Ethridge Davis, *Limited Nuclear Options: Deterrence and the New American Doctrine,* Adelphi Papers No. 121, Winter 1975/76 (Dorking: IISS Adlard & Son Ltd.).

[16]Soviet accuracy figures are from *The Strategic Balance for 1978,* International Institute for Strategic Studies, London.

[17]John Newhouse, *Cold Dawn* (New York: Holt, Rinehart & Winston, 1973).

[18]Arthur J. Alexander, *Decision-Making in Soviet Weapons Procurement,* Adelphi Papers nos. 147 and 148, Winter 1978-79 (Dorking: IISS Adlard & Son Ltd).

[19]Ibid., pp. 25, 34; and Arthur J. Alexander, Abraham S. Becker, and William E. Hoehn, Jr., *The Significance of Divergent U.S. U.S.S.R. Military Expenditures,* A Rand Note N-1000-AF, February 1979, pp. 32, 38-41.

[20]David Holloway, "The Soviet Style of Military R&D." Prepared for the Cornell-Rockefeller Workshop on Decision-making for U.S. Programs of Military R&D, 1978.

[21]Annie Kriegel, "The Nature of the Communist System: Notes on State, Party, and Society," *Daedalus,* Fall 1979, 146.

[22]Shapley, "Technology Creep . . . Two Future Arms Control Problems," *Science,* p. 290.

[23]Ibid., p. 290.

[24]Allison, *Essence,* pp. 138-39.

[25]Thomas C. Schelling, "Reciprocal Measures," 862-914.

[26]Most recently, Defense Secretary Brown has offered the following justification for modernizing the U.S. ICBM force, including the MX. In his annual posture statement he said, first, that assured destruction of Soviet population and industry alone was no longer a "credible" doctrine; second, that the United States should be able to deter, by being able to retaliate against, a wide range of Soviet limited nuclear attacks; and, finally, that "a decision not to modernize the ICBM force would be perceived by the Soviets and perhaps by others as demonstrating U.S. willingness to accept inferiority, or at least as evidence that we were not competitive in a major (indeed what the Soviets have chosen as *the* major) area of strategic power." *Department of Defense Annual Report, Fiscal Year 1980, Harold Brown, Secretary of Defense,* pp. 75-79, 118 (Washington, D.C.: U.S. Government Printing Office).

[27]Christopher Wright, Carnegie Institution. Private conversation.

[28]For discussion of the U.S. penchant for advanced technology, see Col. Richard G. Head, "Technology and the Military Balance," *Foreign Affairs,* April 1978, and Alexander Flax's reply, *Foreign Affairs,* Fall 1978, pp. 207-211. For discussion of the Navy and aircraft, see Deborah Shapley, "Fighter Dispute Raises Questions about Navy's Future Role," *Science,* 24 (March 1978): 1317-19. For discussion of the "strategic culture" as a factor influencing each side's arms and arms control postures, see Thomas W. Wolfe, *The SALT Experience* (Cambridge, Mass.: Ballinger Books, 1979) pp. 106, 331.

[29]Albert Wohlstetter, "The Delicate Balance of Terror," *Foreign Affairs,* 37:2 (January 1959): 211-34.

[30]Leslie H. Gelb, "A Glass Half Full," *Foreign Policy,* 36 (Fall 1979): 21-32.

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DAVID K. STOUT

The Impact of Technology on Economic Growth in the 1980s

There is, it seems to us,
At best, only limited value
In the knowledge derived from experience.
The knowledge imposes a pattern, and falsifies,
For the pattern is new in every moment,
And every moment is a new and shocking
Valuation of all we have been.

T. S. Eliot, *East Coker*

First Principles

In the equilibrium growth models beloved of economists in the past, the long-term ("natural") rate of economic growth equaled the sum of the rates of growth of the working population and the "rate of technical progress," provided governments managed demand so as to maintain full employment. There are three related drawbacks to this simple-minded view. First, labor is not homogeneous. People have skills and take time to learn new ones, so that more or less unemployment in one part of the labor market and excessive pressure of demand in another commonly accompany industrial change in advanced economies. Second, national governments *cannot* any longer guarantee to manage demand so as to maintain its rate of growth at the "natural" rate, because to do so is to strain the ability of labor to adapt to the changing composition of that demand, to stoke up inflationary pressures, perhaps to weaken the balance of payments, or to run up against limits to the supplies of energy. Third, "*technical progress*" is not an independent, given force. It is the rate at which a bank of *technical knowledge* is applied—a bank whose assets now run well ahead of the present rate of withdrawals. The pace of technical progress is in fact the central variable to be determined, not a given factor in the growth equation. The pace is faster when, as now with the microprocessor, there has been a leap ahead in applicable technical knowledge. It is faster when, as now, competition is active, nationally and internationally. Its pace is moderated, on the other hand, by lack of confidence in the rapid, sustainable growth of demand that was the order of the day in the fifties and sixties. It may be further cabined and confined by the

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relative immobility of labor and capital in the face of the rapid changes in the relative importance of different industries and different skills that technical progress entails.

The Outlook for Technical Progress

The pace of advance in potentially applicable technology has been bewilderingly rapid in the past thirty years and appears still to be accelerating. The vision that Joseph Schumpeter had of widely separated major innovations—steampower in the nineteenth century, or electricity and the automobile early in this century—followed by long waves of application in new products, new processes, and new vertical linkages between providers of economic inputs and outputs, still fits today's and tomorrow's world of large-scale microminiaturized integrated circuits with their almost limitless potential applications. But the scope of digital technology; the almost zero cost and size of the hardware; the indefinite economies of scale and diversity of application of standard programs in communication, provision of information, and control; and the safety, speed, flexibility of operation, greater adaptability to individual users and reliability, and lower energy needs that it permits—all make this present addition to the bank of technology much richer than any that has gone before. In the four large fields of automotive products, consumer goods, communication, and engineering processes, the microprocessor will probably be ubiquitously visible, with a market in these user industries of more than $15 billion a year, in less than ten years' time.

Even so, this is not the only such wave that will be rolling through our economies in the eighties and nineties. It will itself overlap with and combine with prodigious developments in lasers and fiber optics in the fields of medicine, molecular biology, "wet" chemistry, microphotography, printing at a distance, cable communication, traffic control, metalworking, retail distribution, and visual and auditory entertainment. And close upon these, other waves will follow in biotechnology and in new and renewable sources of energy.

Caught as the developed world now is in a web of energy shortage, environmental disamenities, stagflation, a seeming fall in the long-term productivity trend, and a new and threatening imbalance of living standards and growth opportunities between the industrialized, the oil-rich, and the newly industrializing countries on the one hand, and the impoverished populations of the Third World on the other, it is impossible to see clearly the contribution these new technologies will make to our lives, or to take the exact measure of the new problems of adjustment they will bring.

We can be reasonably sure of some things. Failures of aggregate demand growth in the near future will lengthen the long wave but not absorb its momentum. There are some feedbacks. The rapid increases in productivity and living standards in economies where competition drives the diffusion of technology will lessen inflation and so raise somewhat the permissible growth of overall demand. On the negative side, the increased obsolescence of existing human and physical capital will tend to outrun the natural pace of labor movement and reequipment by way of training, retraining, and capital replacement, and this will slow up the pace of change. It is probably a mistake to extrapolate past

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trends in the maximum comfortable speed of structural change and to assume the existing set of government adjustment policies. But if we do so, we find that the acceleration of productivity growth (and to a lesser extent new product development) will lead to political and social impediments to the application of intelligent electronics. We are far from ready, through our educational systems, our mechanisms for income redistribution, our attitudes to work and leisure, and our techniques for financing reequipment, to ride the top of the wave.

One stark fact that makes this inevitable is that, whatever might be potential *productivity* growth using microchips, *output* growth for most economies will be constrained in the foreseeable future by supplies of energy and by the 10 percent or so a year increase in the relative price of nonrenewable fuels.

In the equilibrium growth scenarios of the past, the growth of the labor force was one of the twin determinants of economic growth. So dramatic are the savings of industrial and clerical manpower in the new revolution that, energy requirements aside, the effective constraint this time is likely to be the mismatch between traditional skills and the newly necessary skills, in programming, in personal services, in interfacing between the intelligent machine and the user, and in providing for new-found leisure. To use the fashionable terminology, the growth of *demand* for adjustment will be formidably fast; the growth of *supply* of adjustment—through education, changing trade union organization, multiskill training, and reductions in working time—may lag a long way behind in all but a handful of the most adaptable and successful economies.

What we shall probably have to come to terms with in most of the advanced industrial countries over the coming ten years is an odd, indeed unprecedented combination of rather slow growth of output (reined back by the price and availability of energy) with the very rapid spread of new technologies of a dramatically labor-saving kind. Living standards will rise quite sharply. Until the energy constraint is lifted, probably in the mid-1990s, the growth in welfare will need to take the form of increases in leisure time and in the diversity of consumer products rather than in the volume of output in basic industries. The most important economic problem that individual Western governments will face will be the problem of fair allocation of income and effort as some skills become obsolete, and demand cannot be created *ad lib* to reabsorb those unemployed.

I expect the close relationship that has existed in the past between the growth of output of manufactures and the growth of productivity to break down as competing innovators develop the possibilities of the microchip in a slow-growth environment. This is a direct consequence of the special nature of microelectronics. The technological leaders, the VLSI circuit-makers for instance, are not this time all in the United States. Competition is international and fiercely joined for a worldwide industrial market. The rewards for the swiftest are prodigious, because of the pace at which the capacity of integrated circuits is increasing and the almost unlimited economies of scale in the production of units whose raw material costs are infinitesimal.

Even if output growth in the user industries is relatively slow, the effect of the microprocessor on their costs of production and the quality and versatility of their products is so great that demand for the microchip will grow very fast. In a host of potential applications, heavy capital investment is not required. Typi-

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cally, the ratio of labor to capital will fall, but the ratio of capital to output will not rise correspondingly. The rate of substitution of the chip will be limited in the short run by the costs of developing the "software"—the appropriate programs and the sensors, actuators, and peripherals that interpret the computer or the memory unit. But there are large potential economies of scale here too, as users learn to adapt their processes and products to standardized microelectronic packages.

The two main inhibitors of diffusion of the new technology within particular industrial economies will be the slow reaction times (and lack of knowledge) of management and the fear of unemployment. Managerial inertia and ignorance are not endemic in any economy. In most cases, successful competition will speed up diffusion, redistributing demand toward those producers who are quickest to apply the new technology. Worker resistance to the redundancy of many existing engineering skills is a much more potent inhibitor, particularly in economies where labor is organized along occupational rather than industry lines. (Japan has the double advantage of industrial unions and a strong tradition of corporate responsibility for the workforce, leading very large companies to diversify and to create new markets as labor demand falls in the old.)

The economies where labor resistance is potentially most severe are those with a history of low growth—like the United Kingdom—where structural unemployment and underemployment has not been offset by a rapid growth of world market share and domestic demand. A vicious circle of slow growth threatens such open economies if they should fall, for this reason, further behind the expanding technical frontier. The danger is clearly understood by union leaders in Britain, but they have to exert all their influence to forestall resistance to change on the factory floor. The companies that tend to lead the way are those in which management keeps its workers informed in advance of the options the company faces, and involves them in the formulation of corporate plans. The challenge posed by the new technology is less one of commercial judgment than of good industrial relations in all its aspects.

Institutions and attitudes are slow to change, even with the best efforts of governments, unions, and management. There is a limit—set deep in the systems of education and industrial training—to the speed with which new skills can be acquired as old ones become obsolete. There may therefore be an "optimum" speed of adjustment in an economy that is slower than the speed that is forced upon a relatively rigid industrial structure by the pace set by international competition. Three American economists, Nelson, Peck, and Kalachek, noted twelve years ago that

> among the main required adjustments [to new technology] are the reallocation of labor and other resources and . . . assuring that growth in aggregate demand matches the expansion of potential. If these mechanisms do not work well, much of the potential gain of technical progress will be dissipated in unemployment, and a policy of encouraging even more rapid technical advance scarcely would be rational. A current body of thought [this in 1967] maintains that automation is rapidly overbalancing these adjustment mechanisms and bringing on an era of high unemployment.[1]

Writing before the advent of energy shortages, resistant inflation, and massive payments deficits, they could confidently conclude that "no such dismal future"

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lay ahead: the faster productivity rose, the more the government should permit demand to grow.

The policy response nowadays is not so clear-cut. Compensatory demand growth increases energy demands: government efforts have to concentrate on developing alternative energy sources. Technical change creates severe shortages of some skills alongside surpluses of others: income differentials and retraining programs have to be developed to help to eliminate these imbalances.

The actual changes in occupational structure seem certain to outrun the capacity of all but the most successful and adaptable economies to adjust. The social and political tensions created may be expressed in increasing pressures for protection in potentially high-technology user industries, added to the existing protectionist lobbies in senescent industries, where world demand is growing slowly and where production has shifted to newly industrializing countries in South East Asia, Latin America, and Central Europe.

The form that adjustment assistance is likely to take in the high-technology industries of the West is not the kind that will slow down the pace of change, however. Governments are likely to vie with each other to promote research and development and to help national companies to establish a strong domestic position, and to entice international companies to locate. Many of these national efforts will cancel each other out, but, unlike traditional forms of protection, this kind of industry assistance will tend, on balance, to speed up the rate of transfer and diffusion of new technology from wherever it originates.

There are two powerful additional reasons why the new high technology is likely to spread rapidly throughout manufacturing and services, in spite of the present obstacles to world economic growth. First, there is already plenty of evidence within the United States of cooperative changes in industrial structure in response to intense Japanese competition and, in some cases, technical leadership. The association of Motorola, Fairchild, and a number of smaller companies in "Silicon Valley" to compete with Japan in semiconductor design and manufacture is a case in point.

Second, in many sectors of manufacturing where barriers to new entry have been high because of very high initial capital requirements and economies of scale in the mass production of standardized products, the versatility and flexibility of the microchip provides a seemingly limitless variety of often quite small-scale and individual applications to new products and to systems like word-processing that can be developed by quite small new companies. The changed industrial structure that will result from this type of entry will be one in which there is a phase of intense competition based on innovation. The new entrants are not inhibited by the effects of the new technology on a large existing workforce. Established firms will be likely to try to meet that challenge to their market share by more rapid product diversification (alongside productivity improvement), in order to reduce the scale of redundancy that results. The effects of this competitive process can already be seen in the appearance of automated, small-batch production, at costs commensurate with mass production, in the development by small companies of products that work in conjunction with home TV consoles, for example, and in the rejuvenation through digital technology of a market as closed to new entrants in the past as the watch industry.

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Earlier, long waves of innovation multiplied "muscle" and added to the advantages of very large-scale operation. The present wave augments "brain," and makes possible the economic decentralization of processes. In consequence, the spread of new technology into both consumer and producer goods will be limited not by the oligopolistic structure of the user industries, but by the supply of entrepreneurs and the availability of often quite small doses of venture capital.

The Impact of New Technology on Industrial Structure

The most dramatic aspect of microelectronic technology is its pervasiveness. It permits and even requires repeated changes in the design of systems that once were laid down for twenty or thirty years at a time.

The price of integrated circuits has been steadily halved every two years since the early 1960s as their capacity has increased. Very soon the relative cost of the microelectronic hardware will be negligible. Microcircuitry now enables digital processes to be applied to telephone communication, filing, editing, printing and publication, production and quality control, measurements of all kinds, information storage and retrieval, translation, and calculation. Incorporation of such processes into a familiar product like a TV set improves the product by reducing the number of its parts and increasing its reliability, as well as reducing assembly costs by as much as 70 percent. Over and over again, the *product* innovation of the microprocessor manufacturer is the *process* innovation of the user, as when, for example, he reequips his production line with a computer-numerically-controlled machine tool.

The potential rate of change of productivity growth and quality improvement, using successive generations of programs and logic arrays, is so fast that many investment decisions are becoming less "fixed," less unalterable. The life of capital, in fact, is shortened by the annual rise in the superiority of the latest alternative equipment. This increased obsolescence makes capital more mobile. As a consequence, investment decisions may in general be taken in the face of greater uncertainty than before, or over a shorter planning horizon.[2]

Since intelligent electronics can provide just about anything people may want to buy, and the microchip has negligible transport costs, it is not going to be possible to predict which final products one country will specialize in, and which it will import, on the basis of its endowments of different scarce factors of production. It seems certain that there will be radical changes in the competitive advantages of both developed and developing countries, and that these will lead to severe adjustment problems as existing industrial structures cease to be relevant. Many a new product will have a very short life, and trading advantage will go the country that develops it first. After the fashion of Schumpeter's successful capitalist entrepreneur,[3] the nation whose exports grow fastest will be the one that manufactures products early in their life cycle and whose companies can diversify continuously into other new products, enjoying temporary monopoly profits and leaving the older markets. Which particular products leader economies and follower economies will produce depends on their relative capacity to move resources quickly and on where the products are in their life cycles. Latecomers are bound to try to follow the leader, or to lose the market altogether, because in most cases, the cost reductions made possible for the innovator far

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overbalance any countervailing advantage the followers may have through lower real wages. Wage stickiness guarantees that the international diffusion of so extremely productive and ubiquitous a technology will be swift.

It cannot be assumed that the traditional technological leader, the United States, will continue to lead across the whole gamut of applications. For one thing, the potential applications are legion, and relatively few of them depend on large initial scale. The United States has had by far the largest share of the early generations of hardware, by virtue of her clustered supplies of electronic skills that followed from the space program. Today there are areas where Japanese companies have taken over the technological leadership. One example is in the supply of equipment to manufacture semiconductors, to print circuits with minute line width. Recent explanations of Japanese advantage run in terms of better organization, not "factor endowment": for example, quality control is better because the system designer, the manufacturer of the circuit, and the industrial user all work together as a joint management team to ensure high product quality.

It is impossible to predict precisely how international trade flows will be changed as the wave of microelectronics spreads across bank after bank of products. There is a strong element of chance—what happens to be the home base of the innovator of some particular application of microelectronics. As in the physical or biological sciences there tend to be more breakthroughs in the countries with well-endowed laboratories, so with engineering innovations and relative national spending on R&D. Yet, a Nobel Prize for physics or a crucial breakthrough in speech recognition may still come out of a simple laboratory or a small company.

There are one or two guiding principles. Technology, and its embodiment in semiconductors, has never been so internationally mobile. It seems now that only *labor* is a geographically fixed factor. Thus we can expect to find, and are finding, some very high-technology production based even in newly industrializing countries like Korea. Regardless of traditional specializations, products like toys and automobiles are nowadays footloose and "culture-independent": the industrialized countries can expect to enjoy no automatic advantage in their sale. Other families of products and related software, like entire educational systems or medical diagnosis and treatment systems, are "culture-dependent," and here the industrialized nations can hope to find some large export opportunities. Finally, the pace of innovation is very fast, and the largest risk is of one's product being superseded during the development stage. It is important, therefore, to search for gaps in *future* markets that can be filled almost before potential competitors know they are there. The rewards for imagination, lateral thinking, and the combination of apparently separate disciplines and technologies will never have been so great as they become in the next ten or fifteen years.

The Impact of New Technology on Employment

In the face of new technology, the greatest uncertainty, the main social tension, and the most important challenge to government policy are the consequences for employment. In the past, the fears of long-run unemployment as

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a result of technical progress and automation have been unfounded. There have been three main reasons for this. First, changes in the distribution of labor demand have not, in general, been faster than changes in the structure of the labor market, by virtue of retirement, training, and change of occupation. Second, the real income gains to organized labor as a consequence of increased productivity have been spent on new and more and better consumer goods. Aggregate demand has grown more or less in step with the growth of productive potential. Third, output growth and employment were not restrained by inadequate capacity or by long-run shortages of raw materials or energy. As a further bonus, the growth of world trade was high until the 1970s, so that new outlets for industrial production developed in the course of international specialization and freer trade.

In all these respects the prospects for employment are now less assured. First, as computer control and robotics displace repetitive human attention and effort, the pace of increase in productivity in long-established industries will tend to outstrip the speed with which labor skills can change. Second, real income gains may not lead quickly to increases in consumer demand: the propensity to save is raised both by uncertainty about the future rate of inflation and fears of unemployment. Third, for the time being, at least, investment in capacity expansion is inhibited by worldwide uncertainty about demand, in the light of the continuing world energy shortage.

If overall unemployment rises as a consequence of rapid technical change imposed on an energy-constrained growth rate, the development of new and renewable sources of energy ought to go ahead faster, and popular concern about the environmental risks involved in nuclear energy may also diminish. On balance, relative demand stagnation does not seem likely to limit employment beyond the mid-1980s.

Furthermore, during these years there are already clear signs that the supply of labor in the "formal" labor market will fall in relation to the potential number of employees somewhat more quickly than it has in the past thirty years. This is because the demand for leisure will be further increased by the higher material living standards of the employed population and by the complementarity that will exist between leisure time and the new consumer products that microprocessors make possible—home computers, leisure applications of the TV console, programmable musical instruments, and many other "intelligent" products.

The greatest challenge to, and potential inhibitor of, the new technology is the speed with which skills can change in response to changes in their relative demand. Many existing skills, such as traditional information-handling, typing, automobile maintenance, and mechanical engineering, will be a glut on the market, while numeracy, quick-wittedness, and fluency will be at a premium. In the past, a skill acquired at the beginning of one's working life kept its economic relevance until retirement. On some estimates, so quickly will industrial structure and processes of production change in the future, that the life-expectancy of a skill may be only ten years or less.

The obsolescence of physical capital leads to early scrapping and replacement. No such option exists for human capital. Nor can we rely on the institutions that determine relative wages to bring about appropriate changes in

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skill-mix in time. Within many trades unions there are pressures to retain both existing differentials and existing job structure that cannot be reconciled.

Within the services sector there may be some of the largest increases in productivity. In retail distribution, for example, the laser wand at the check-out counter can displace many jobs in stock control, labeling, and purchasing. On balance, however, employment opportunities in services will almost certainly grow on the back of increased industrial productivity as they have in the past. A far wider variety of professional, leisure, and social services—labor-intensive because they entail personal contact—will be demanded.

The greater the capacity of industrial economies to adapt by changing skills and educational curricula, by training programs leading to the acquisition of *ranges* of potential skills, and by greater geographical and occupational mobility, the faster the new technology will be adopted and with less inequity in consequent income and employment opportunities.

* * *

I feel greatly optimistic about the new "long wave" of intelligent electronics and the further waves of renewable energy and biotechnology that are visible behind it. Our three appalling capacities for self-destruction remain—overpopulation, irreversible environmental damage, and nuclear war. None of these three nightmares is brought closer by the latest advances in technology. On the other hand, the possibility of the kind of society imagined by Plato, Swift, Rousseau, and John Stuart Mill—in which work is done for pleasure, and increased personal fulfillment is found in the harvesting of education through communal and individual activity—is brought a little nearer.

It would be more comfortable if progress occurred smoothly, at a pace well adapted to society's capacity to absorb it, but it does not, and it is better that it should come suddenly than not at all. The new technology is itself energy-saving. It will greatly extend the range of goods. It will provide nonmaterial benefits by improving health, increasing leisure, alleviating pain, adding to the powers and perceptions of the disabled, and greatly extending education and private access to information.

A fashionable "humanist" viewpoint is that microprocessing will change everything except everything that matters. This judgment seems to me to be shallow and false. As always in the past, technological change brings with it new problems, like the danger of a dichotomy arising between the few who can manipulate the new technology and the many who are left behind. That is a problem for the present adult generation. It should not be for the next, whose education is now beginning and who can still acquire the flexibility and ingenuity that the artificial magnification of intelligence demands, and who can learn in time how to value the leisure that we have lacked.

REFERENCES

*[1]Nelson, Peck, Kalachek, *Technology, Economic Growth and Public Policy* (Washington, D.C.: Brookings Institution, 1967), p. 113.

*[2]There are important exceptions, of course. For example—as in telecommunications—the system adopted may have to be compatible with thousands of complementary investment decisions taken at other times and in other countries.

*[3]Joseph A. Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper & Row) ch. 7.

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EDWARD E. DAVID, JR.

On the Dimensions of the Technology Controversy

DISCUSSIONS OF TECHNOLOGY often seem like discourses on good and evil. There are those who see only good in it, who insist that more and better technology will resolve most of today's problems. Others see only evil; they believe that technology is a principal cause of most of society's ills. Arguments along this continuum usually end up somewhere in the middle, with a compromise solution that seeks to balance costs and benefits. Much is hidden within the terms "costs" and "benefits"—for example, at whose cost are the benefits achieved and where do they fall? Actually, the technology controversy is multidimensional. It is important to sort out these various dimensions so that discussion can lead to more definitive prescriptions. It is the purpose of this essay to address three of these dimensions briefly and to examine the resulting implications.

Technology is an abstraction: it is the collection of techniques, methods, and know-how to achieve particular ends. It is not synonymous with hardware but rather includes such diverse elements as information handling, medical practice, health care, mathematically based analytical techniques, engineering synthesis and design, problem-solving algorithms, computer software, and systems incorporating these—elements that hardly seem susceptible to common conclusions or logic. In fact, technology in this broad sense can scarcely be considered in isolation from its cultural and societal surroundings. In this natural setting, technology and many of the issues concerning it are altogether more understandable. The dimensions to be discussed comprise the setting wherein the broad elements of technology seem less disparate and can therefore be addressed with a greater degree of generality.

Certainly, technology has relevance to most of the vital issues of our times: it bears on the economic health of the nation and the world and on relations between nations, and it is at the root of national defense and world stability (or instability). Should we as a society aim at increasing dependence on technology in the traditional pattern to sustain our standard of living, or should we look elsewhere, toward minimal or alternate technology?

A similar question was raised in the fifties and sixties, when there was a substantial attempt to infuse science and research into developing countries, an endeavor that was at least partially successful in creating research facilities that could produce capable researchers. The hope was that this educated cohort

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would lead the way toward industrial development. This hope went largely unfulfilled. Observers at the time believed that the nature of the science and its related technology was inappropriate (too sophisticated, perhaps) to be used constructively in those societies at that point in their development. This is not far from the current theme of "appropriate technologies," except that the diagnosis is now being applied to both developed and developing countries.

In retrospect, this earlier experience reveals an interesting divergence of views. Despite the doubts of observers here, the *cognoscenti* of the developing countries considered the research institutes that were established in the fifties and sixties to be largely successful in bringing self-respect and prestige to their nations and in establishing standards of excellence and achievement. The recent North-South dialogues and the UNCSTD (United Nations Conference on Scientific and Technological Development) affair seem to point in a similar direction, namely, that developing countries desire sophisticated technology. Advanced technology for production, they believe, will enable them to compete in world markets, but it will also validate their indigenous talents, skills, and intelligence. Yet, there is a spectrum of opinion that local, decentralized, rural technology is preferable. In many ways this divergence is akin to the controversy over whether agriculture or industrialization should have priority in development. It also raises the issue of the political acceptability of "appropriate technology" in nations striving for recognition.

Thus the question of technological style cannot be answered without bringing in economic, social, and political factors. A question better than the one posed earlier might be: What type of technologies are suitable for societies at various levels of maturity? There may be no general answer. It may be that any well-considered answer will devolve to a case-by-case examination of technologies in which the nontechnological factors play a major role.

Technology, beyond its relevance to worldly matters, also has a major impact on science. Science and research are sometimes equated, though incorrectly. Much research is spurred by technological needs or by newly available instrumentation. Research can be either a contribution to the archives of scientific knowledge, or it can produce an appropriable technological application, or both. The point is that the health of science depends heavily on the state of technology. Very little science is independent of technology, either as animator or as contributor through new capabilities, particularly instrumentation and new phenomena, as typified by lasers and monochromatic light. Thus the progress of science at any time is intimately related to the style and pace of technology.

Technology is at the core of many of the seemingly broader issues of our time, as well as the health of science itself. Confidence in technology as a societal and scientific resource is widespread among engineers, some scientists, and the general public. Is this confidence justified? There are nagging doubts, for technology seems to have a dynamic of its own. It does not necessarily take us where we want to go as a society. The state-of-the-art and natural law constrain technology to certain paths. Admitting that, to what degree is it feasible to shape and program technology toward what society sees as desirable goals? Are the time scales of societal desire and technological development compatible, or do societal tastes change so rapidly that technology can only respond with so-

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cially obsolete options? What mechanisms might be used to bend and shape technology on society's behalf? Present efforts are feeble, or certainly ineffective, with the exception of the market mechanism, which seems to operate well in some segments. Technology assessment has not been effectively implemented, and may depend too heavily on predicting the unpredictable. The current political mechanisms of the nation and the world seem profoundly unsuited to the task. The challenge for society at large seems similar to that for management: how to be selective and efficient without stifling creativity and responsibility. It may well be that, in our quest for answers, we are searching in the wrong dimension. We may be depending too little on individual integrity, insight, and inspiration, and too much on process and system. Let us now turn to the dimensions which may provide the setting for technology in its broadest sense.

The Credibility of Experts and Public Participants

One of the most critical issues facing problem-solvers and decision-makers is whom to trust. Until recently we have depended on the elites of science and engineering for advice and counsel, a tradition that goes back to 1863 when the Congress established the Academy of Science as an independent advisory body. More recently the President's Scientific Advisory Committee enjoyed a ten-year tenure. But this traditional dependence is declining. PSAC has been disestablished, and although the Academy has in recent years given increased service to the Congress, it is now only one among many voices.

The scientific and engineering community itself has contributed to the public skepticism about expertise. The public and its representatives have discovered what those inside the community have known for many years, and indeed have taken for granted as a desirable and essential feature of the research and development process: the community is seldom of a single mind, even on questions at the core of scientific knowledge, particularly when these have social and economic consequences. Preconceptions and prejudices have not been purged. There are powerful driving forces to postulate models that suit not only factual data but also moral and ethical considerations. This response to controversial public issues has emboldened politicians and citizen groups to question the validity of scientific and engineering-based recommendations.

A closer look reveals a fundamental distinction. Often, near-agreement on technical matters can be achieved within the community. Such topics as the validity of data, measurement methodology, limitations on conclusions, objectives of experiments, theoretical concepts, and so on create little controversy once protagonists discuss their differences. Often, the residual disputes result in further research or new designs that either settle the dispute or more frequently yield an overarching concept. This process is altogether more successful than attempts to interpret the meaning, significance, or implications of research findings, for it is here that the community has exposed its divisions.

It has been said, unfairly, in my opinion, that a congressional committee or a government agency can find a "qualified" person with technical credentials to testify to anything desired. This perception has been augmented by the traditional American distrust of elites and sympathy for the apparent underdog. It is

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politic for public figures to take the side of the unconventional or minority view, particularly where interpretations of, or application to, societal affairs are involved. This trend is progressing, and it may further undermine the scientific community's credibility when it is called on to give advice and testimony regarding the nature of technological choices and associated scientific "fact."

The trend toward "advocacy science" is significant. It is akin to the trend in industry to apply "business principles" to research and development. Both are efforts to bend technology toward what are seen as desirable or profitable goals. It is natural in this process to call on advocates and managers to control and focus R&D activities. The appointment of business school graduates, lawyers, and administrators as executives responsible for charting research and development in industry is one result. A statement on research leadership made recently by the Industrial Research Institute points to the difficulties for industrial development raised by this trend. It states in part:

> Courses in the business and management faculties of universities, as well as special programs and seminars, have historically stressed the more formal business skills. Only recently have we begun to see a more conscious effort placed on teaching senior executives how to manage change and technological innovation. There is then an urgent need for the development and dissemination of such training programs at the highest levels in U.S. industry.
>
> In any enterprise the onus is on the C.E.O. to study, understand, and implement the techniques of innovation, particularly in high technology corporations. The C.E.O. is the main agent of change and his strategy must reflect this if innovation is to persist.[1]

A corresponding trend is the appointment of social advocates, lawyers, and historical scholars to lead federal laboratories and institutes. Technical advisory committees to the Office of Technology Assessment and to federal departments have increasing representation from public interest groups, labor unions, and the general public. Many of these people are from the legal profession or the humanities, are part of the political scene, or have general qualifications only. They lack the credentials for dealing with technical subjects, although some may be able to use technical terminology. However, they bring to the advisory and decision process a wider point of view and can put technology in the broader natural setting.

This dimension, with experts at one end and generalists at the other, raises the issue of which group predominates, not only in decision-making on the uses of technology for public and industrial purposes, but also, and importantly, in deciding priorities and directions for research and development itself, including regulation of laboratory experimentation. This issue reaches across the spectrum, from basic research to product and process development. The issue of public, or lay, or humanist, participation is not itself in question, since that seems firmly established in most forums. Rather, it is the degree of influence and the question of qualifications of the participants.

Past experience with large-scale technological program planning has not been gratifying. The national cancer research program is a good example. The enthusiasms whipped up by interested laymen led to a massive attempt to plan the effort by well-qualified participants who would be overseen by "representative" observers and organizations. That program has not produced the hoped-

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for results. The attempt was probably scientifically premature, encouraged by the overoptimism of lay enthusiasts and by political motivations. Similar cases of technological overreaching, encouraged by wishes and desires not backed by hard technical judgments, can be found in many other instances, both in government and industry.

Technology: Master-minded or Spontaneous

It has been said that technology spontaneously generated from new ideas and inventions has its own momentum. In some instances there is such momentum. Technological projects are aimed at producing a product, a service, or a manufacturing technique. Some observers believe that such efforts are not likely to be successful or sustained over the long period of development, with its inevitable ups and downs, unless the project has a "champion" who can attract the necessary support. Typically, ten years or more pass between initiation of a project and its first operational deployment. (In Project Apollo this interval was about eight years.) During this interval the public mood can change dramatically, as it has in the case of the prototype breeder reactor. Reference to technological momentum is usually applied to weapon-system programs such as the M-X missile, but examples can also be found in the energy and health fields, and almost all other fields as well.

This process of buttressing support, marshalling favorable arguments, and involving other interests such as foreign governments, as NASA has done in its LANDSAT program, does indeed impart momentum to projects. It is well known among administrators, budget reviewers, and executives that the most difficult chore is to cancel an ongoing effort. Various mechanisms, other than executive fiat, are used to aid in shutting down such efforts. Among these are various analytical techniques based on econometrics. However, we should note here that the most difficult situation arises when technological success is coupled with economic, political, or social failure, or when these nontechnological factors are in dispute. Today, the technological imperative is not as compelling as it once was. Public opinion seems more volatile than ever, so it is difficult to build a lasting support base for technological projects. These are also becoming election issues and thus are subject to political debate every two to four years. Yet, the momentum problem has hardly disappeared.

At the opposite pole from the momentum concept is the idea of master-minding technology. In some fashion, society should specify the desired technological performance, and engineers should produce it. This paradigm has been applied, for example, in the case of emission controls in automobiles where emission levels were set legislatively. In that case, the technology generated was the catalytic converter, to be followed shortly by the "three-way" catalyst tied to electronic feedback controls. The idea of agreed standards or targets that technology strives to meet has a certain validity on its face. The public or business desires are stated, and implementation is left to technical people, who presumably are best suited to fashion technology to satisfy those desires.

As a general technique, however, the method has pitfalls. In the Department of Defense the master-mind technique has been incorporated in a "requirements" process. Requirements for new weapons or weapon systems are set

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forth in a formal document specifying performance, based on studies of military missions to be performed by the weapon or system. Development and production is then contracted to the defense industry. Though this description is oversimplified, it captures the essence for our purposes. In the opinion of many who have participated in this process, it is a substantial contributor to the cost overruns and technical failures that have been too frequent in military procurement.

The difficulty is that requirements may reflect military desires and needs, but not the achievable state of the technological art. Of course, efforts are made in the requirements process to consult engineers and scientists to constrain this effect. But "technological *macho*" often prevails among those who have witnessed startling progress-on-demand in the past. There is often, in addition, encouragement from defense suppliers who are anxious to advance technology using proprietary results or know-how from their own laboratories. Regardless of the criticism of such processes, these suppliers have on occasion produced credible results, as in the case of emission controls. The danger is that we will specify unrealistic wants and desires leading to costly or unsuccessful developments and foreclosing more realistic alternatives.

The spontaneity of technology and the push-momentum it creates are opposed by forces that have been characterized as master-minding. The extremes on either side are seldom at issue: rather, we should be searching for the proper balance point. This will be influenced by the social and economic risks posed by the particular spontaneous technology on one hand, and the size of the technological leap required by the master-mind on the other. These matters are largely judgmental, though there are institutional aspirations for methods to quantify them.

Technology in the Cultural Dimension

On one end of this dimension is the influence of technology on cultures; on the other, the influence of cultures on technology. These effects are difficult to measure, but they are clearly present.

Technology is a product of the culture from which it is spawned. Design of equipment, such as Japanese electronic products, shows the style and custom of the originating society. Soviet technology tends to be rugged and massive; the contrast with the Japanese product is startling. This cultural influence goes beyond appearances; it affects function as well. This implies that the character of a technology must have some degree of cultural compatibility with the society in which it will be used. Where a product or service is developed and used within the same society, this necessary compatibility is often expressed in terms of markets and customer acceptance. The close association of marketing and technology in the process of innovation is well known and acknowledged today. In fact, much of industrial research and development today is influenced by market factors. Marketing departments have an increasing say in corporate strategy specifiying the research and development program.

When a technology is introduced from outside a society, cultural compatibility is often missing, causing a rejection phenomenon. This is one of the major difficulties in international technology transfer and foreign policy. The infusion of alien technologies often causes a culture shock of greater or lesser seriousness.

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A substantial part of the federal regulation of technology-related business activity arises from cultural factors. Concerns about the factors of scale, concentration, and market competition have led to a variety of regulatory laws and rulings as well as self-styled single-interest groups who participate in the federal rule-making procedures. Much of this activity is related to traditional American distrust of concentrations of power. The antitrust laws and preferential treatment of small businesses with respect to taxes and labor laws support these traditional views, as do, on an informal level, increasingly popular anti-establishment and anti-institutional views and actions. The total effect of federal regulation on technology is in dispute. Much has been written about this matter, and it is clear that the influence is substantial.

At the opposite pole, technological effects on culture are well known and much discussed. The influence of communication and transportation technology on commerce, recreation, urban form, and personal habits has been documented by social commentators and by government agencies that are again interested in regulation and control of such influence. Some of the efforts toward regulation and control are indirectly related to technology through economic influences. The attempt to constrain health-care costs, for example, has created a complex system of controls aimed at medical technology and its uses.

A substantial impact of technology on culture results from the typical progression of technology in the marketplace. This progression is tied to wide and extensive use of the technology. Typically, the price of new hardware and services is high when they are introduced and decreases over time. But this is dependent on wide usage of the product (or service) and competition for the market. Wide usage provides the pioneer with revenue to improve the product by technological development. It also allows him to achieve economies by large-scale production and to maintain his share of the market by meeting competition with reduced price. Although it is oversimplified, this paradigm has operated in numerous instances, minicomputers being a recent and spectacular example.

The drive for broad usage of a technological product or service can have a considerable cultural impact. Minicomputers are changing the nature of office and clerical work and the lifestyles of the employees involved. Realization of the mutual impact of culture and technology has led to a variety of attempts to quantify and codify technological choice. On the purely economic level, cost/benefit techniques augmented by sophisticated models have been utilized. These have played a substantial role in national defense strategy, in energy supply-demand futures, and in formulating fiscal and monetary policies. However, most practitioners will admit that such models are suggestive and not definitive. The models themselves tend to be primitive and are subject to continuing refinements. It is best to consider them as aids to thought, not as replacements for it.

In many businesses, economic analyses based on the so-called discounted cash flow method are used. This technique discounts future benefits at a rate related to expected inflation and postponed returns. Such calculations are the bane of research and development, for these activities are investments in the far future where benefits are difficult to estimate and easily discounted. Such analyses may be a considerable factor in the shortened outlook for research and development programs in industry.

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Beyond economic accounting, there is the human risk. In recent times there have been attempts to calculate the risk to people of various technological options. These lead to probabilistic estimates of "excess deaths" and impairments to health. The same caveats hold here as for the use of models as a whole. There is little evidence that probabilistic thinking motivates individual actions or societal action. Risk models have been used principally in pejorative discussions of various technologies related to energy, automotive safety, and health-care procedures.

Certainly, one difficulty with most such models is the high level of aggregation. Macroscale results say little about individual choice and action. Even on a collectivist, aggregated basis, model results depend on the validity of data and projections of the future, both points of traditional weakness.

An important perspective on the culture-technology interactions is revealed by divergence between subjective and objective probabilities. Psychological measurement indicates that these can diverge substantially. And it is usually the perceived probability rather than the actual that controls human behavior. Regardless, it is of overriding importance to recognize that there are wide divergencies in individual behavior. Preserving individual choice is altogether more important than achieving some average or aggregated index. Reconciling individual choice and action with macromodels and their teachings is a puzzle worth deep consideration.

* * *

The three dimensions addressed concern people, process, and cultural influences in technological decision-making and deployment. Laying out such dimensions as a setting implies that technology is viewed as a national resource. From there it is an easy jump to the view that special mechanisms are needed to guide technology along desirable paths. The opposite, however, seems to be the better recommendation. The usual mechanisms of society should be relied on, since it is unwise to separate technology from its societal setting. Such a separation is exactly the effect to be avoided if technology is to serve society.

Needless to say, societal mechanisms for decision-making and governance abound. In the United States and most of the West these mechanisms are pluralistic and are tailored to the wide divergences of thought and action so typical of these societies. It is in just such circumstances that technological activities thrive and where morals and ethical judgments can best be applied to them. The principal resources in this process of societal modulation of technology are the qualities of individuals—responsibility, integrity, insight, and inspiration. We can do no better than to depend on these and to allow leeway for them to be exercised.

However, there is not a large cohort of the population that considers itself qualified to judge on technology in its societal setting. Even those who seem qualified come at the subject from very disparate backgrounds. Perhaps the two most divergent are the engineer and the social scientist, or perhaps the humanist or generalist. In any case, such differences in viewpoint have prompted today's major educational attempts toward the public understanding of science, which

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are actually usually focused on technology. These efforts have made wide use of all the media. Some have been quite successful, but all seem to lead to further efforts at bridging the gap of understanding. There is increasing evidence in the media markets that these efforts are leading more and more people to participate in informed debate and discussion. Beyond this, formal education of the liberal tradition is incorporating attempts to provide technological literacy.

Finally, it is worth noting that the conjunction of technology and human desires represents a fundamental meeting between the natural law and the reaches of the human mind. Mental constructs including perceived needs and visions of a better world are constrained only by human imagination and concepts. Technology is constrained by the physical laws of nature. How these are reconciled has always been a major determinant of the health and progression of civilizations and culture. This will continue to be so.

References

[1]Industrial Research Institute Position Statement on Innovation within the Corporation, March 1979.

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ELTING MORISON

The Uncertain Relation

ONE OF THE GREAT AMERICAN ENGINEERS of the last century, Alexander Holley, wrote an article in 1876 called "The Uncertain Relation Between Science, Engineering and Art." In it he said:

> The adaptation of machinery can only be perfected by him who, as it were, enters into it, making it an incarnation of himself, an enlargement of his own organism. Oliver Wendell Holmes has described this putting of his life into a rowing boat—his every volition extending as perfectly into his oars as if his spinal column ran down the center of the keel. So the thoughtful locomotive driver is clothed with all the attributes of a power superior to his own, except volition. Every faculty is stimulated and every sense exalted.

In this passage there is an exhilaration that is often taken to be the product of some sort of dark Faustian fix. There may be something in it. But it can also be ascribed to one of man's endearing qualities: the persistent urge to make something better for and of himself. Either way, the passage also contains a quite unambiguous warning. The machinery must always be arranged so that a whole man can fit and act comfortably within it. Not only must the spine run down the keel, but room must be found for the cerebral cortex, the central nervous system, the gizzard, and all the rest of it. The adaptability and control of the machinery depend on respect for this requirement and its inclusion in the design specifications.

At the time Holley was writing, and in the machine he was writing about, this condition seemed almost possible to achieve. But even then there were those who had doubts about the existing fit between men and the machines they built for themselves. Exactly a hundred years ago a physician named George Beard explored what he called the destructive nervousness of the American people. The causes, he said, were the steam engine with its jolts of transforming energy; the division of labor made possible by the steam engine; the pocket watch that organized experience into arbitrary quantities of time; and the telegraph that overloaded newspapers and the central nervous system with a surfeit of random signals. The result was that "civilization hangs by a thread."[1]

Others bore witness at intervals in the ensuing years, and it is worth a moment to consider the burden of their testimony. In 1901 Henry Adams concluded that society was about ready to "break its damn neck." This was demonstrated by "an arithmetical calculation from given data, as for example from explosives, or electrical energy, or the control of cosmic forces." The line

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of argument was, essentially, that the increasing capacity to manufacture power moved, in the absence of appropriate control, steadily toward multiplicity—fragmentation—and a consequent disordering of the arrangements designed to give structure to men's lives. "We know," he concluded, "so little and our power is so great."[2]

Twenty years after Adams, Lewis Mumford described a deadness in the center of things because "business, technology and science not merely occupied their legitimate place, but took to themselves all that hitherto belonged to art, religion and poetry. Positive knowledge and practical action, which are indispensable elements in every culture, became the only living sources of our own."[3]

And, finally, in 1945 Alfred North Whitehead said that conditions had changed more in the last fifty years than they had changed in the preceding three thousand. The energy in technology and science had broken through all the received traditions, and the choice was now a new form of society, or "mankind may all but exterminate itself and desolate this planet."[4]

However much these observers, spread over three-quarters of a century, differ in detail and *timbre*, they come together on their essential findings. Things are falling apart into what one of them called a dissolved society. The obvious cause is the expansion of the machinery. Patching up the received order will not serve the occasion. The choice is now absolute—either a total disintegration or the construction of a new dispensation clear and firm enough to control the machines.

In the interests of further argument, let it be assumed that for this volume of *Daedalus*, devoted to issues raised by modern technology, this categorical choice represents the only central issue. Beside it, other aggravating concerns—what to do about the energy shortage, pollution, our capacity to sustain life beyond the point where it is worth living—are tertiary matters, temporary distractions that can more easily be dealt with after the design of the new dispensation is completed.

On the assumption that the choice will be taken against the dissolution of the planet and for the building of some new form of society, how does one proceed in the task? No man in his right mind would try to describe the exact shape and detailed content of this new dispensation or culture. But it is possible to suggest some preliminary steps in the exercise.

To begin with, there are some current assets that should not be discounted because of untoward present circumstances. There is, first, the fact that we now know a great deal about the true conditions of our world. The inquiring mind working in the field of science has accomplished a great deal in the past hundred years. From it we have obtained the systematic means for disinterested investigation, for full and fair analysis, for well-founded conclusions and measurable prediction. By its exercise we have cut through guesswork and penetrated illusion to reach accurate descriptions of the real world we inhabit. From it, also, we have gained reassuring evidence that order is a condition of nature. And from its repeating successes we have obtained the confidence—almost the self-induced sense of obligation—to find out more.

These epistemological achievements have been made possible because the workings of the physical world proceed in their essentials, in the way the mind

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works, by logical processes. Thus, to get at the riddle of the surrounding that has frustrated men for so long, it seems possible now for the first time to think it through. Not only am I because I think, but the way I think is the way all that is real turns out to be. It is a stimulating concept. We may still be placed a little lower than the angels, but we are now out in front of them by at least a head. And that well-informed, thoroughly trained, resourceful head is obviously one essential instrument to use to prevent the breaking of the damn neck.

There is more, however, than epistemological delight in the findings produced by such effective thinking. These findings can be applied through machinery to do work. The remarkable industrial development is the product, in part, of economic interest, sporadic ingenuity, entrepreneurial skill, and the tendency to look for some easier way. But the prime mover has been the advance in what is known about the structure of the world. Machines are simply formal expressions of what is understood about the materials, forces, and principles of organization in nature at any given time. As the understanding of the physical world advances, so the machinery in its variety, size, power, and complexity is increased.

The cumulative effect of this process can now be seen to be extraordinary. Machines now do much of the very hard and dangerous work that men used to do, and certain kinds of work that men could not ever do before. Reckoned in those goods and services that all but eremites set store by, the lot of everyone has been measurably improved. The fact is that the machines in their sum have produced a new kind of environment. The terms for living day-to-day are set not so much by the intractable conditions of the natural world as by an engineering system. There is a certain grandeur in this achievement. And in the achievement there is also a novel and saving opportunity. Where men in the days of Genesis and for long thereafter had to build their forms of society to fit into a world they could not do much about, it is now possible to change the engineering system to serve a form of society one would like to have.

That opportunity is, at the moment, more a prospect than a fact. Indeed, the past century has demonstrated that the ordinary constraints—the test of the market, legislative limitation, mathematical models for future development, and executive skill—can do little more than direct the technology into the path of its own accelerating development. As of now, the machinery has no larger context than itself to work in. So questions of design and organization tend to be posed as technical objectives—enlarged capacities, improved efficiencies, and the continuous search for the technical virtues of added sophistication and elegance. And all that seems to lead to multiplicity and fragmentation, and possible desolation, and a scheme of things that hangs by a thread.

It is therefore necessary now to arrange the apparatus in accordance with a more generous organizing principle, to put it in some context of larger purpose. That is, to develop the new dispensation from which can be derived the criteria for the design, control, and change of the engineering system so that it will do work in support of a more humane intention.

As a start for building this dispensation or new culture, one can go back to Alexander Holley and his proposition that the controlling factor in machine design was the requirement that a whole man must fit and act comfortably within the mechanism; and his further proposition, suggested in his title, that to

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fulfill this requirement, knowledge of science and engineering had to be qualified by the findings of art. The idea is that art is the surest source of information about the nature of the human dimensions.

Since that time, of course, by borrowing the intellectual procedures employed in the study of the physical world, we have developed new means to investigate the nature of man. But so far these procedures, as reflected in the social sciences and the scholarship of the humanities, have not supplied the necessary information. What is required is something less cautious, analytic, and cool, a far more telling account of the human conditions. Art—the products of poetic energy in whatever form of expression they may be put forward—still seems the most effective counterweight to what is known in science and engineering.

Three contributions art can make to the building of the new forms of society may be cited. First, to make its points, art works at the development of the particular case. In so doing, it loses something to the rational authority that can logically demonstrate, from stable evidence produced by repeating experiments, the force of a general proposition. But where the realization of the case is sufficiently complete, it can indicate, by implication, the presence of a more general truth. And in its concentration on the single instance, art can demonstrate the power of the particular: the fact that, while the terms of life may be set by statistical probabilities, experience for the individual is made up of a series of discrete and real occasions. It thus vividly preserves the sense of the immediate and specific, the steadying concreteness of actuality that gets muffled up and insulated in the generality that is an abstraction. This direct feeling for what actually happens in the individual situation is a condition that has to be taken into account in any organizing form for contemporary experience. It presents the claim for variation within the order of technological structure, and introduces constructive surprise within the solemn regularities of machine performance.

The material art works with is derived, ordinarily, from the perception of the senses—what a man can take in. It therefore seeks to keep scales and proportions that are life-sized. Engineering applications, derived as they are from the superior energies of nature, can produce impressive amplifications of mass, weight, power, and speed. Art can supply the standards—the quality control—to prevent these amplifications from being carried out to the full extent of their logical conclusions. When there are clear statements of the human dimensions, such as art introduces, against which the amplifications can be measured, the point of dangerous exaggeration in scale and proportion can be determined—exaggeration here meaning the point beyond which men cannot handle or stand the machinery.

And, finally, art—poetic energy—in pursuit of its objectives, must take a position, establish a point of view. Its business is presumed, as Noah Webster said, to pertain to the beautiful. And so, fortunately, it does. But beauty is not so much a thing in itself as a product of arrangement, some sort of order. Where science can reveal the structure of nature simply by scrupulous reports on the play of forces within a settled and prescribed system, art, seeking structure for human experience, must to a far greater degree introduce its own arrangements for the materials at its disposal.

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It does so, in part, by eliminating the extraneous elements that clutter up any human occasion and, in larger part— as E. M. Forster urged, "only connect"—by suggesting an organizing form for the interaction of the elements that remain. To accomplish this work of selection and connection—to bring things together in revealing arrangement—it is necessary to discriminate among the constituent energies in an event and to assign values to them, values not only for certain aesthetic requirements, but for the actions and purposes that make up the event. That is, to assess those conditions that serve the human interest and those that may destroy that interest. So art, in seeking appropriate ordering forms for experience (satisfying compositions), puts forward a scheme of values for the conduct of affairs and demonstrates the necessity of introducing some point of view—an interpretation of the meaning of an event—as an organizing principle.

Any future culture—itself a composition for the ordering of human activity—must, as Whitehead said, be shot through with "unflinching rationality."[5] But if it is to provide a decent fit for men and machinery, it must find some way to go beyond those logical calculations of operating efficiency and cost/benefit ratios that, taken as organizing principles, have produced the present disorder. In that culture, room has to be found for the determining play of poetic energy.

It is probable that these claims for art will seem considerably inflated. And, surely, since the Greeks first insisted upon taking the aesthetic contribution seriously, it has had a history of uncertain influence. In more recent times the record is hardly reassuring. For this, there are several reasons. Like almost all other modern endeavors—scientific investigation, medicine, athletics—art as a formal practice has become specialized, committed to technical refinement, and introverted and separated to an extent from its constituency. It has further suffered because its findings, subject to varying interpretation, have yielded ground steadily to the more verifiable and immediately useful findings of science. And, still further, the developing technology, with its own form of organization, has presented a forbidding surrounding. Art, as a formal practice, has therefore been used to supply distracting decoration or trivializing concealments for the operation of machinery, or to present oblique criticisms of the conditions created by the productive power of the industrial plant.

Taken, not as formal practice, but as the natural expression of the poetic energy in every individual, art has had at least as difficult a time. The modern means of production have left small room for the exercise of Holley's "every sense and faculty" or of what was called craftsmanship—the way man arranged the materials he worked with. Similarly, in the design of those abstract technical systems for the ordering of human activity—merchandising, transport, health care delivery, and so forth—there is small room for the influence of private aesthetic exercise. The projection of these networks, in one gloomy observation, is that men will become nodes in a communication system, or, in another observation, drones in a computerized hive.

Given these conditions, historic and contemporary, it appears that those setting out to build a "more durable culture" for men's activities in these times have their work cut out for them. But the intent here has not been to establish the odds. It has been rather to indicate that the critical issue in this building business is where men start from, that is, whether they are determined at the outset to find the proper balance among science, engineering, and art for the structure of the culture they build.

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References

[1]Henry Nash Smith (ed.), *Popular Culture and Industrialism* (New York: Doubleday & Co., 1967), p. 57.

[2]Harold Dean Cater (ed.) *Henry Adams and His Friends* (Boston: Houghton Mifflin Co., 1947), p. 508.

[3]Lewis Mumford, *The Golden Day*, White Oak Library Edition (New York: W. W. Norton, 1934), pp. 275-276.

[4]Lucien Price, *Dialogues of Alfred North Whitehead* (Boston: Little, Brown & Co., 1954), p. 344.

[5]C. P. Curtis, Jr., and Ferris Greenslet (eds.) *The Practical Cogitator* (Boston: Houghton Mifflin & Co., 1945), p. 522.

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WALTER ROSENBLITH

A Note on Engineering and the Other Professions

IN HIS PREFACE TO THE FALL 1963 issue of *Daedalus*, "The Professions," Stephen Graubard noted that the "professions are as characteristic of the modern world as the crafts were of the ancient." He drew on Alfred North Whitehead to summarize the distinction between them: a craft is "an avocation based upon customary activities and modified by the trial and error of individual practice"; a profession is "an avocation whose activities are subject to theoretical analysis." The issue dealt not only with the traditional three learned professions—theology, medicine, and law—but also teaching, science, the military, psychiatry, city planning, and politics. "Science" was obviously intended to refer to the natural sciences and not the social sciences. Even economics, a field in which a Nobel Prize is now awarded, did not figure. A hard-cover edition of the issue published in 1965 added chapters on engineering and architecture, and concluded with the essay, "Journalism: Art, Craft, or Profession?" Management, interestingly enough, was not included, though it was a visibly emerging profession.

Whitehead's use of the term "theoretical" must be interpreted broadly if we are to justify the inclusion of professions other than the traditional ones. Yet, include them we must, for in an industrial society, especially in its post-industrial phase, the professions multiply, and relations between them become increasingly complex, even if we do not include the so-called paraprofessionals.[1]

As medicine, theology, and law exist to serve the public, so, it is argued, all other professions must have this as their prime purpose. A profession, then, is characterized both by mastery of a specific body of knowledge acquired in a more or less tightly prescribed course of study, and by being regulated (licensing is only one form of regulation) by some public body that both sanctions and circumscribes certain of its activities so that the public can be protected.

In our increasingly man-made world, human needs—both primary and sociocultural—are more and more filled by technology in the form of hardware, software, or biomedical technology; in short, by the application of scientific knowledge to practical purposes. The industrial and military spheres traditionally have been based on engineering technologies. Now, service and administrative activities are rapidly becoming professionalized; in the process, these emerging professions incorporate technological elements in everything they do, from the way they educate to the canons of ethics they seek to formu-

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late. Engineers increasingly are brought into contact with ever larger numbers of other kinds of professionals. These will very often respect the engineer's technical expertise, but most often will treat him as merely a technical consultant. The ambiguity of the term "engineering"—which means anything from technicianlike activities in sales and service to activities indistinguishable from those engaged in by scientists—does not make interprofessional relations easier.

Because there has been a gradual shift of emphasis in engineering careers from knowledge of things to knowledge of human and societal constraints, as Vannevar Bush had anticipated, the views of Hardy Cross take on new meaning: "Many engineering problems are as closely allied to social problems as they are to pure science." Engineers now confront issues that deal not only with energy, new materials, communication systems, computers, information handling, and life-support systems, but with the pervasive effects of engineering systems on human health and the environment, on privacy and death, and on human mobility, climate, and industrial innovation. Engineering activities in scale and effect are now capable of affecting both society and nature substantially. And even as we are far from understanding these interactions in our own society, with its fragmented and competing constituencies, the countries of the Third World clamor for the transfer of our technologies, not always asking whether these are appropriate to societies with different natural settings, cultural traditions, educational systems, human resources, and purposes.

Thus far we have rarely been able to devise ways, mechanisms, or institutions to facilitate fruitful cooperation between the engineering profession and other professions, many of which—particularly those derived from biological or social science disciplines—are in a state of extraordinarily rapid change. This problem is of course not unique to engineering; it exists in some form at the interface of any two professions that differ in their capacity to compare in quantitative terms their analytical approaches or outcomes, taking into account desirable values and acceptable risks. The influence of engineering is so pervasive today because technology affects, and is affected by, practically all professions with the possible exception of theology. Yet, even theology seems increasingly to be shaped, in some quarters, at least, by man's technological habitat.

There is an imperative need to sensitize future engineering professionals for work with professionals from other disciplines. What strategy may be used for this purpose? During preprofessional and professional maturing phases, differentiation is most often emphasized rather than the type of cooperation so obviously needed in most public or private institutions. Hence, ways must be found to do more than assess the social changes—options, benefits, costs, risks—to which a new technology may give rise, a task so difficult, that success often eludes even the hardest working task force, laboring under the most advantageous auspices. Excellent committees and groups established by the Commission on Sociotechnical Systems of the National Research Council (the operating arm of the National Academy of Sciences and the National Academy of Engineering) or the Office of Technology Assessment (the analytical arm of the U.S. Congress) can attest to the difficulty.

There is, of course, no universal solution to the problem of institutionalizing effective interprofessional cooperation. It would seem, however, that continuing education may present a unique set of opportunities in this area. Contin-

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uing education in its multiple forms and under its many auspices most often aims, rightly, at bringing professionals up-to-date in their respective fields. However, it might be useful also to invest some of the time of professionals—especially those who see themselves as working for the improvement of the human condition—in interdisciplinary workshops where men and women would together study case histories, plan exercises, and reexamine the design of systems and practices that have a major technological component. Some of the exercises could be directed toward a specific purpose on the agenda of a particular institution, municipality, or region; others might be more purely academic. If such exercises are to be useful, however, their purpose must be twofold: to acquaint the participants with the skills, strengths, weaknesses, and value structures of other professionals, and to make each reexamine his conceptions of what the various professions can contribute to a common undertaking.

Engineers—whether from industry, government, consulting firms, or universities—have a great deal to gain from such cooperating groups. There seems no better way to acquaint other professionals with the methods of engineering analysis and design, to raise questions that engineering itself cannot answer, and to enable engineers to contribute significantly to a more systematic formulation of issues that concern other professions. Out of such meetings may come more realistic educational proposals for future engineers. It will acquaint them with perceptions of technological problems as other professions see them, and with the institutions they will have to work with. Finally, and most important, it will contribute to a better understanding of the ways in which economic, social, health, and political issues are necessarily present in most technological decision-making.

References

[1]A numerical estimate from the area of health may serve to illustrate this point: there are approximately half-a-million physicians and dentists in the United States, and there are roughly five million people working in health-related occupations, a figure that includes the groups called the "allied health professions."

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Notes on Contributors

W. O. BAKER, born in 1915 in Chestertown, Maryland, is chairman of the board of Bell Laboratories. Dr. Baker has served on the President's Science Advisory Committee and several other White House boards. He has contributed to *Perspectives in Polymer Science* (1966), *The Technological Catch and Society* (1975), *The Random House Encyclopedia* (1977), and *Science and Technology in America—An Assessment* (1977).

HARVEY BROOKS, born in 1915 in Cleveland, is Benjamin Peirce Professor of Technology and Public Policy at Harvard. He has served on the President's Science Advisory Committee and several other national boards, and is the author of *The Government of Science* (1968).

EDWARD E. DAVID, JR., born in 1925 in Wilmington, North Carolina, is president of Exxon Research & Engineering Company. He was science advisor to the president of the United States from mid-1970 to 1973.

N. BRUCE HANNAY, born in 1921 in Mt. Vernon, Washington, is vice president of research and patents at Bell Laboratories, and has served on many national and international science advisory boards. He is the author of *Solid State Chemistry* (1967), editor of *Semiconductors* (1959) and several volumes of the series *Treatise on Solid State Chemistry* (1973-76), and co-editor of *Electronic Materials* (1973).

DAVID S. LANDES, born in 1924 in New York City, is Robert Walton Goelet Professor of French History at Harvard. He is the author of *Bankers and Pashas* (1958), *The Unbound Prometheus* (1968), and *History as Social Science* (1971).

ROBERT F. MCGINN, born in 1941 in Jersey City, New Jersey, is adjunct professor of Industrial Engineering and Engineering Management, Engineering-Economic Systems, and Values, Technology, and Society at Stanford University. He is the author of *Nietzsche's Social and Cultural Thought* (forthcoming) and several articles on technology and philosophy.

ELTING MORISON, born in 1909 in Milwaukee, is Kilban Professor, Emeritus, Massachusetts Institute of Technology. He is the author of *Turmoil and Tradition* (1960), *Men, Machines and Modern Times* (1966), and *From Know How to Nowhere* (1976).

ROBERT S. MORISON, born in 1906 in Milwaukee, is a visiting professor at Massachusetts Institute of Technology. He is the author of *Scientist* (1964) and has written articles on neurophysiology, science policy, and biomedical ethics.

WALTER A. ROSENBLITH, born in 1913 in Vienna, is provost and Institute Professor at Massachusetts Institute of Technology. He is the author of *Sensory Communication* (1961), and has served on numerous technical committees and advisory boards, including the President's Science Advisory Committee.

DEBORAH SHAPLEY was born in 1945 in Washington, D.C. She is a senior associate at the Carnegie Endowment for International Peace, on leave from *Science* where she covers international affairs, national defense, and science policy. She served as a consultant to the secretary of defense in 1977.

Continued

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DANIEL T. SPRENG, born in 1940 in Berne, is manager of the department of ecology at Swiss Aluminum Ltd., Zurich. He is the author of several papers on materials science and energy accounting.

DAVID K. STOUT, born in 1932 in Bangor, North Wales, is economic director of the National Economic Development Office in London. He is the author of several articles on economic issues and policies.

ALVIN M. WEINBERG, born in 1915, is director of the Institute for Energy Analysis, Oak Ridge Associated Universities, in Tennessee. He is the author of *Reflections on Big Science* (1967) and co-author of *The Physical Theory of Neutron Chain Reactors* (1958).

LANGDON WINNER, born in 1944 in San Luis Obispo, California, is associate professor of political science and technology studies at Massachusetts Institute of Technology. He is the author of *Autonomous Technology: Technics-out-of-Control as a Theme in Political Science* (1977) and is currently at work on a study of technological design and the quality of public life.

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In addition to contributors, symposium participants included:

ALFRED CHANDLER
Isidor Straus Professor of Business History
Harvard Business School
Harvard University

NORMAN DAHL
American Academy of Arts and Sciences

LOREN GRAHAM
Professor, Science, Technology, and Society
Massachusetts Institute of Technology

ALBERT HIRSCHMAN
Professor of Social Science
Institute for Advanced Studies
Princeton University

GERALD HOLTON
Mallinckrodt Professor of Physics and Professor of the History of Science
Harvard University

MICHAEL MACCOBY
Director, Program on Technology, Public Policy, and Human Development
John F. Kennedy School of Government
Harvard University

MERRITT ROE SMITH
Professor, Science, Technology, and Society
Massachusetts Institute of Technology

RAYMOND VERNON
Herbert F. Johnson Professor of International Business Management
Harvard Business School, and
Clarence Dillon Professor of International Affairs
John F. Kennedy School of Government
Harvard University

JOSEPH WEIZENBAUM
Professor of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

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